NASA TECHNICAL REPORT

NASA TR R-431

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COMPUTER AND PHOTOGRAMMETRIC GENERAL LAND USE STUDY OF CENTRAL NORTH ALABAMA

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(NASA-TR-R-431) COMPUTER AND PHOTOGRAMMETRIC GENERAL LAND USE STUDY OF CENTRAL NORTH ALABAMA (NASA) 114 p HC $5.25 CSCL 08B

N75-13372

Unclas
H1/43 06137

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • OCTOBER 1974

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. TR-431	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE Computer and Photogrammetric General Land Use Study of Central North Alabama		5. REPORT DATE October 1974
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) R.R. Jayroe, P.A. Larsen, and C.W. Campbell		8. PERFORMING ORGANIZATION REPORT # M130
9. PERFORMING ORGANIZATION NAME AND ADDRESS George C. Marshall Space Flight Center Marshall Space Flight Center, Alabama 35812 Aerospace Environment Division		10. WORK UNIT NO.
		11. CONTRACT OR GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, D.C. 20546		13. TYPE OF REPORT & PERIOD COVERED Technical Report
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This report is made available under NASA sponsorship in the interest of early and wide dissemination of Earth Resources Survey information and without liability for any use made thereof.

16. ABSTRACT

The object of this report is to acquaint potential users with two computer programs, developed at NASA, Marshall Space Flight Center. They were used in producing a land use survey and maps of Central North Alabama from Earth Resources Technology Satellite (ERTS) digital data. The report describes in detail the thought processes and analysis procedures used from the initiation of the land use study to its completion, as well as a photogrammetric study that was used in conjunction with the computer analysis to produce similar land use maps. The results of the land use demonstration indicate that, with respect to computer time and cost, such a study may be economically and realistically feasible on a statewide basis.

17. KEY WORDS Remote Sensing Mapping ERTS Land Use Computer Classification Pr ,rams Photo-Interpretation Photogrammetry	18. DISTRIBUTION STATEMENT Distribution Categories: 13

19. SECURITY CLASSIF. (of this report) Unclassified	20. SECURITY CLASSIF. (of this page) Unclassified	21. NO. OF PAGES 114	22. PRICE $4.50

MSFC - Form 3292 (Rev December 1972)

For sale by National Technical Information Service, Springfield, Virginia 22151

ACKNOWLEDGMENT

Dr. Jayroe and Mr. Campbell wish to express their appreciation to Mr. Jack A. Jones and Ms. Dianne Moore of the MSFC Computation Laboratory, Engineering Computation Division, and Mr. Melvin R. Phillips, Computer Sciences Corporation, for their efforts and assistance in obtaining the computer results.

Mr. Larsen gratefully acknowledges the assistance given and suggestions made by the following individuals during the preparation of the photogrammetric portion of the report: Mr. Edward O. Zeitler of Johnson Space Center; and Messrs James Derington, Charles Dalton, William Vaughan, Edward Dixon, and Dr. Leonard DeVries of Marshall Space Flight Center.

All of the authors would like to acknowledge Mr. William W. Vaughan for his helpful comments and concise review of this report.

In order that referrals can be made to the appropriate person concerning information contained in this report, the photogrammetric section and appendix were written by Mr. Paul Larsen, while the bulk of the computer section was written by Dr. Robert R. Jayroe. Mr. Warren Campbell contributed the sections on the Composite Sequential Clustering Program contained in the computer section.

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COMPUTER AND PHOTOGRAMMETRIC GENERAL LAND USE STUDY OF CENTRAL NORTH ALABAMA

SUMMARY

The report is divided into two sections which describe the photogrammetric and computer land use study respectively, but, as a single entity, the report documents the step by step procedures used in the land use study from its inception to its completion. The land use scheme presented in Geological Survey Circular 671, entitled, "A Land Use Classification System for Use with Remote Sensor Data" by J.R. Anderson, E.E. Hardy, and J.T. Roach [1], was used as a standard for comparison of the land use maps developed from conventional aerial photography and Earth Resources Technology Satellite (ERTS) digital multispectral scanner data of the central north portion of Alabama. The results include land use maps obtained from photo-interpretation of the aerial photography and from two computer programs operating on the ERTS data, as well as area percentages and spectral signatures of the land use categories. Minimum computer time and cost of such a survey are estimated for the entire state, and recommendations are made for additional needed efforts and improvements.

It is worthwhile to mention that data classification or information management programs are one of many tools that are available to an investigator for developing a solution to his problem or particular question, but the programs are not the solutions to the problems themselves. Before contemplating the use of such tools, it would be wise for the investigator to specifically define the objectives to be accomplished, take note of the available resources, and evaluate several alternative ways for accomplishing the desired objectives.

PHOTOGRAMMETRIC LAND USE STUDY OF CENTRAL NORTH ALABAMA

Introduction

A land use study of the central north portion of the State of Alabama was initiated utilizing participants with experience in various technical fields. Two of the participants, Robert Jayroe and Warren Campbell, were experienced in devising automated land use classification schemes which employed digital computer techniques, and which are fed intelligence via digital data tapes obtained by orbiting space platforms. The third participant, Paul Larsen, had experience in the field of conventional photogrammetric engineering.

The efforts of these participants were combined in a local area land use analysis for the purpose of demonstrating the applicability of automated classification schemes and photo-interpretation techniques to such an analysis. ERTS digital tapes, ERTS

imagery, high and intermediate altitude aerial photographs, and ground truth photography were the primary information sources available to the participants while conducting the analysis.

Early considerations discussed by the participants were as follows: (1) What resource should be evaluated in the study, or should the study deal with general land usage? (2) What would the geographic bounds be for the area which was to be automatically classified by computer, mosaicked, and mapped? (3) What was the quality of ERTS data available for the selected area? (4) Was there high altitude aircraft imagery (RB-57), and intermediate altitude aircraft imagery (U.S. Dept. of Agriculture) available of the chosen area? and (5) Which of the available imagery and data would be selected for application to the study? Decisions resulting from these considerations are discussed in subsequent paragraphs.

The primary plan of the project emerged: to develop land use maps by the use of (a) the Spatial and Spectral Clustering Program and ERTS digital tapes of the chosen area; (b) the Sequential Clustering Program and ERTS digital tapes of the chosen area; and (c) aerial photomosaics prepared from vertical imagery resulting from high and intermediate altitude aircraft missions over the chosen area. In addition, the day to day findings resulting from each of these approaches were to be exchanged among the several participants in order to "cross pollinate" and improve the efficiency and potential of the results of each of the three techniques used in the study.

ERTS imagery and digital tapes, for use in the two computerized land use classification techniques, were selected from the November 4, 1972, ERTS overpasses. Accordingly, the high altitude aircraft imagery chosen for use in the preparation of the small scale (1:144,300) mosaic of the land use study area, was that obtained by an RC-8 camera mounted in an RB-57 aircraft flown over the area on November 16, 1971. In this mission, Eastman Kodak Aerochrome Infrared 2443 Film was used.

In addition to the color infrared RB-57 imagery used in the small scale photomosaic preparation of the entire land use study area, black and white aerial photographs made available by the Department of Agriculture were used in the preparation of several larger scale (1:20,000) mosaics of selected portions of the land use study area (please refer to the Appendix). The primary purposes of the mosaics were: (1) to serve as a basis for land use map preparation using conventional photo-interpretive techniques, and (2) to supplement the photographic ground truth of the land use study area, both synoptically at the smaller scale and in considerable detail at the larger scale. The mosaics and the photographic ground truth were of significant benefit in preparing the land use maps resulting from the conventional photo-interpretive techniques, and were equally beneficial when interpreting the map printouts produced by the automated computer schemes from digital tapes.

Early in the project, when the geographical area for this study was being discussed, three small adjacent rectangular areas, approximately 48 statute miles by 33 statute miles (77.2 km by 53 km), across central north Alabama, were considered. Pros and cons of the

land use related parameters of each area were "weighed" and compared so that the best area for the study's purposes would be selected. A 55 statute mile by 33 statute mile (88.5 km by 53 km) rectangular area centered around Athens, Alabama, (Fig. 1) was eventually selected as the study area. Its western boundary was Wheeler Dam; its eastern boundary was Huntsville Mountain just east of Huntsville, Alabama; the northern boundary was the Tennessee-Alabama state line; and the southern boundary was a line approximately 30 miles (48.2 km) south of, and parallel to, the Tennessee-Alabama state line.

At the beginning of this project, some consideration was given to slanting the study towards one specific type of land use such as agriculture, forestry, urban expansion, or transportation networks. After discussion and thought by the participants as to choosing one specific land use for the study, it was mutually agreed that a general land use study covering a variety of specific land uses would more satisfactorily evaluate the digital and photogrammetric techniques for land use applications. Similar work using photogrammetric techniques is reported in References 2 and 3. In addition, a decision was made to adopt the land use classification system specified in the Geological Survey Circular 671, dated 1972, as a standard for all three of the techniques being studied. Circular 671 is discussed briefly in the next Section.

Some loss of photographic detail and degradation of overall image quality may be noticeable in the photographic illustrations. However, readers desirous of studying the original plates, from which the photographs were made for the report, may do so at the author's installation.

Land Use Maps Resulting From Aerial Photomosaics and Single Aerial Photographs

PREPARATION OF AN AERIAL PHOTOMOSAIC OF THE LAND USE STUDY AREA

Purpose: An aerial photomosaic of the Land Use Study Area, shown in Figure 1, was produced (1) to provide a base for conventional land use map preparation, and (2) to provide a useful information source which would be helpful in interpreting the computer classification maps produced by the automatic data classification schemes.

Method of Preparation: Before an aerial photomosaic can be produced, it is necessary to determine what photographic imagery of the area is available, and then choose which of that available imagery will be used to best suit the purpose of the mosaic. To mosaic an area the size of our Land Use Study Area, which is approximately 2,700 square miles or 6,900 square kilometers, it is necessary to choose imagery of a scale such that an excessively large number of photographs are not required.

One good source of current imagery which is available for most of the United States is the Soil Conversation Service of the Department of Agriculture. This agency sells vertical photographs which are taken every few years at a scale of 1 to 20,000. These

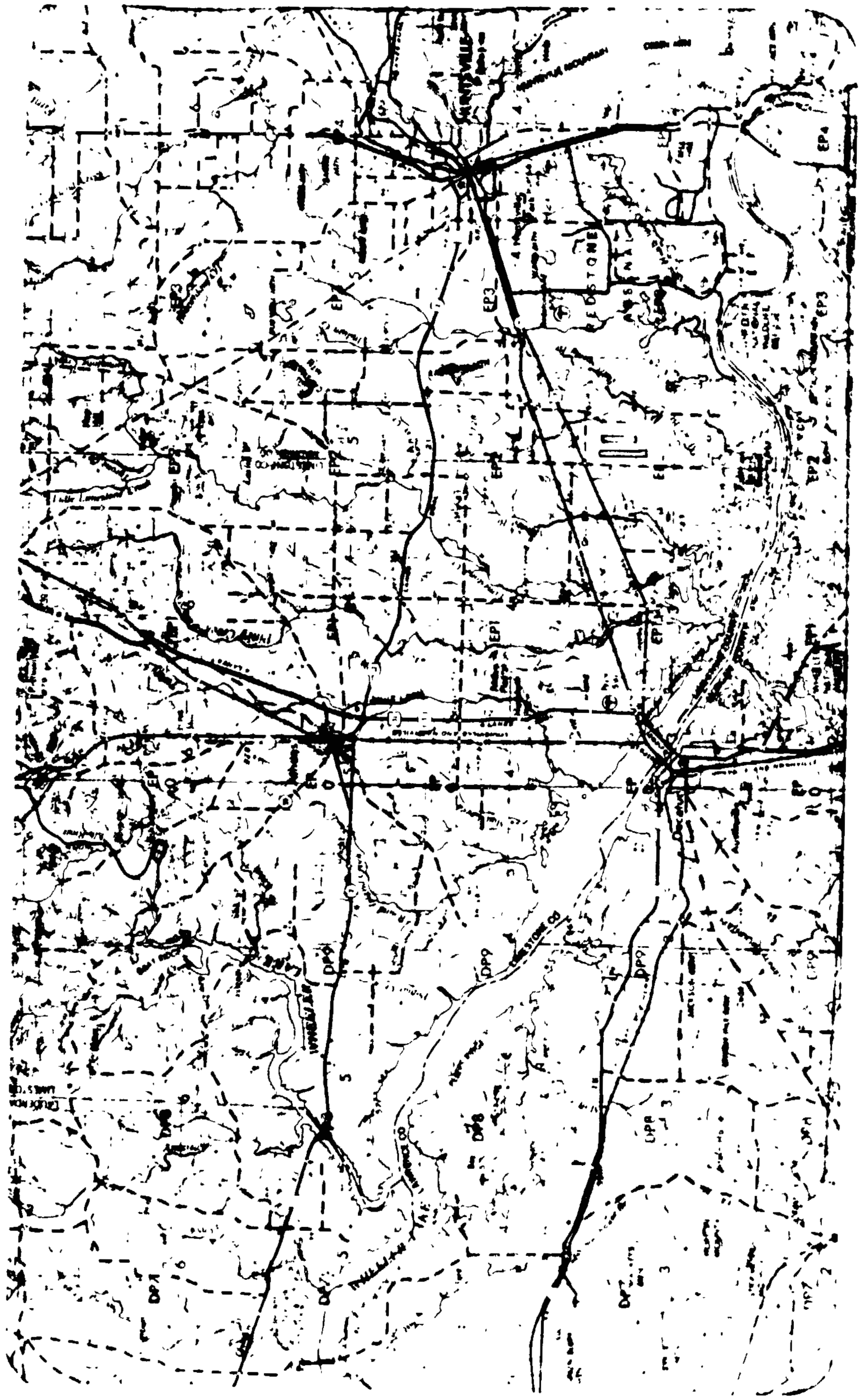


Figure 1. USGS map of land use study area.

were considered, but only for detailed examinations of certain parts of the Land Use Study Area, and not for the overall synoptic view, due to the obvious limitation of space required to lay out such a large mosaic.

Another good source of available imagery was NASA RB-57 imagery obtained as part of NASA's Earth Observations Aircraft Program. Three sets of RB-57 imagery, each of which included the area of the Land Use Study, were located in the Environmental Applications Office of Marshall Space Flight Center. The overflights are specified as follows: Mission 166, Flight 8, flown on May 21, 1971; Mission 191, Flight 1, flown on November 8, 1971; and Mission 191, Flight 4, flown on November 16, 1971. The appropriate frames for these three flights, both the RC-8 camera imagery and the Zeiss camera imagery were reviewed for applicability to the Land Use Study Area. Of the above three flights, Flight 1 of Mission 191, flown on November 8, 1971, was eliminated from contention because of cloud conditions over the eastern portion of the Land Use Study Area. The remaining two flights, the May 21 and November 16 imagery of 1971, were both virtually cloud free and could be used for photomosaic purposes. Of these two flights the November 16, 1971, Flight 4 imagery of the RC-8 camera was chosen, because November 1972 ERTS imagery was selected earlier for use in the automatic data classification schemes to be employed in this cooperative study.

After choosing the November 16, 1971, RB-57 imagery for the mosaic, the next step was to decide which frames were needed from this mission, and then have prints made. The prints were produced in the Photographic Division of Marshall Space Flight Center, by first making 4- by 5-in. exposures of the 9- by 9-in. RC-8 positive transparencies and then enlarging the 4- by 5-in. format up to 8- by 10-in. prints. The component photographs of the mosaic were then prepared, trimmed, feather-edged, and laid using azimuth line control in accordance with conventional photogrammetric techniques. Due to the reduction in format size of the component prints from 9 in. by 9 in. down to 8 in. by 8 in., the resultant scale was 1:144,300 compared to 1:120,000 on the original positive transparencies. The mosaic shown in Figure 2 has been photographically reduced to an approximate scale of 1:586,000. The film in the RC-8 camera in the RB-57 at the time the exposures were made was Kodak Aerochrome Infrared-2443 with an Estar base. While viewing the photomosaic shown in Figure 2, the reader may find it helpful to be aware of the following basic characteristics of Kodak's Aerochrome Infrared-2443 Film. The three layers of the 2443 false color film are sensitive to green, red and infrared radiation instead of the usual blue, green, and red used for normal rendition of the visible spectrum. In the final tranparencies or prints produced from this film, green results from red exposure and red results from infrared and green exposure.

In forest survey work, diseased foliage can be identified and distinguished from healthy foliage by interpretation of infrared reflectance of the foliage as recorded on the film. With this film you can also distinguish between deciduous and evergreen trees. Healthy deciduous trees have a much higher infrared reflectivity than do healthy evergreens. In the spring and the summer healthy deciduous trees show up as magenta or red, healthy evergreens show up as bluish-purple, and dead or dying deciduous leaves or evergreen needles photograph bright green since they have lost their infrared reflectivity. In the fall, red leaves photograph yellow, and yellow leaves photograph white.

Figure 2. Aerial photomosaic of a 2,650 square mile (6,860 square kilometer) land use study area in Central North Alabama.

In the photomosaic shown in Figure 2, the reader, even after brief study, will be able to identify the Tennessee River and Wheeler Lake, running north-westerly in the bottom half of the mosaic. The large city and urban area of Huntsville is seen in the eastern end of the mosaic, and to the southwest of Huntsville is Decatur, on the south side of the Tennessee River. Due north of Decatur is the town of Athens. Other small towns such as Courtland, Rogersville, Gurley, and Lexington are identifiable. Forested areas are recognizable on many parts of the mosaic. A little more careful study will enable the individual to locate highways and railroad beds. Interstate 65, running north-south near the center of the mosaic, was not completed across the Tennessee River at the time this imagery was taken. Huntsville-Decatur Jetport is visible to the south of Highway 72 connecting Huntsville and Decatur, about midway between these two cities. Near the town of Courtland, which is approximately 10 miles south-southwest of the junction of Elk River and the Tennessee River in the southwest portion of the mosaic, can be seen the old Courtland Army Air Base.

In general, grazing areas and rich pasture land in this mosaic show up as shades of pink or red due to the high infrared reflectivity of this type of land. Careful discrimination of tonal qualities allows one to differentiate between the deciduous forests and coniferous forests. To help the reader in locating points of interest in the mosaic, a portion of the 1:250,000 USGS map was included as Figure 1 at a reduced scale.

MAP PRODUCT BASED ON USGS CIRCULAR 671

The United States Geological Survey, in its circular 671 published in 1972, described a Land Use Classification System [1] for use with remote sensor data and proposed it for review and testing. At the outset of our land use study, we decided to adopt the scheme as proposed in circular 671, in view of the large number of land use classification schemes available, all with various advantages and disadvantages. Perhaps one good way to describe this Land Use Classification System is to quote the abstract of the circular: "The framework of a national land use classification system is proposed for testing and review. The classification has been developed to meet the needs of Federal and State agencies for an up-to-date overview of land use throughout the country on a basis that is uniform in date, scale, and categorization at the more generalized first and second levels and that will be receptive to data from instrumented satellite and high-altitude aircraft platforms. The classification system utilizes the best features of existing widely used classification systems to the extent that they are amenable to use with remote sensing, and it is open-ended so that regional, state, and local agencies may develop more detailed land use classification systems, at third and fourth levels, to meet their particular needs and at the same time remain compatible with each other, and with the national system."

A synoptic land use map of the study area, which was prepared from the aerial photomosaic, is shown in Figure 3. The following categories, taken from Level I of Circular 671's scheme, together with their respective color codes, were used: 1. Urban and built-up land – yellow; 2. Forest land – green; 3. Water – blue; and 4. Agricultural

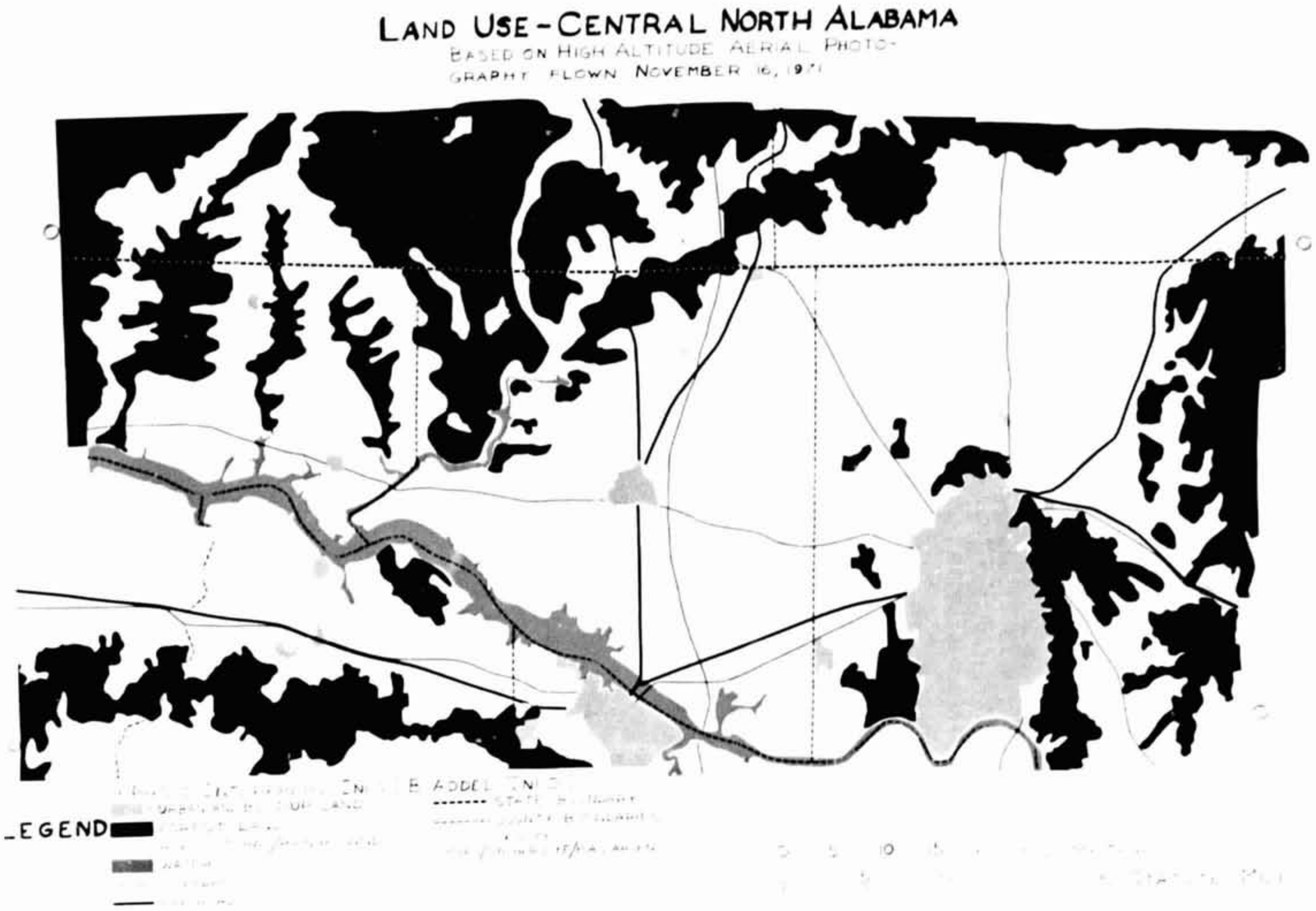


Figure 3. Land use – Central North Alabama.

and Rangeland – white. It is pointed out that in Circular 671, agricultural and rangeland are considered as two separate categories, but for the purposes of this land use map the two are lumped together in view of the scale of the photomosaic from which the map was prepared. The fields and agricultural areas are so small on a map of this scale that it would have been unrealistic to divide them out into the separate categories of agricultural land and rangeland. Also, in this part of the country, grazing fields are very often interspersed among the agricultural or crop producing fields. In addition to the various land use categories, listed above, which have been shown on this land use map, highways were added by using red strips and railroads were shown by using black strips. The other items of information which were shown on the map, but which were not photointerpreted from the mosaic or its component photographs, were county boundaries shown in southern Tennessee and northern Alabama with small black dashes, and the state boundary between Alabama and Tennessee, shown with large black dashes.

This map product, although quite simple and inexpensive, does enable one to quickly assess the extent of the area's primary land uses. It is evident from the map that a little less than three quarters of the area is being used for various agricultural applications, including grazing. A little less than one quarter is forest land, and smaller amounts are occupied by urban and built-up applications such as residential, commercial, industrial, transportation, and institutional. A more precise accounting of the land use components in the area has not been included here since certain land usage category simplifications were made during the map's preparation.

At the time the author prepared this map, based upon the mosaic shown in Figure 2, an accurate recording of time spent on its production was not made. However, during the final phase of our land use study, the co-authors felt that comparative time and material figures for the three mapping techniques would be of interest to the readers. Accordingly, it was estimated that approximately 35 engineering/photo-interpretation man hours and $5.00 in material costs were expended in the production of the small scale land use map of Central North Alabama illustrated in Figure 3.

LARGE SCALE LAND USE MAP OF THE JONES VALLEY AREA

Figure 4 is a map showing the various land use categories existing in an 8.25-square-mile (21.4-square-kilometer) area in southeast Huntsville, Alabama, known as Jones Valley. This map was prepared from a United States Department of Agriculture aerial photograph taken at a scale of 1:20,000 on December 7, 1970, but it is shown in Figure 5 at a reduced scale. The USDA serial number of this photograph is HM-5MM-63. On December 7, 1970, sequential coverage of most of the city of Huntsville was obtained in addition to coverage of other parts of Madison County.

One reason for selecting a photograph of this scale for use in our land use study was to demonstrate the ease of preparing a land use map of an area, using very basic and fundamental engineering tools and principles. In preparing this map, sequential photographs taken before HM-5MM-63 and photographs taken subsequent to it in the

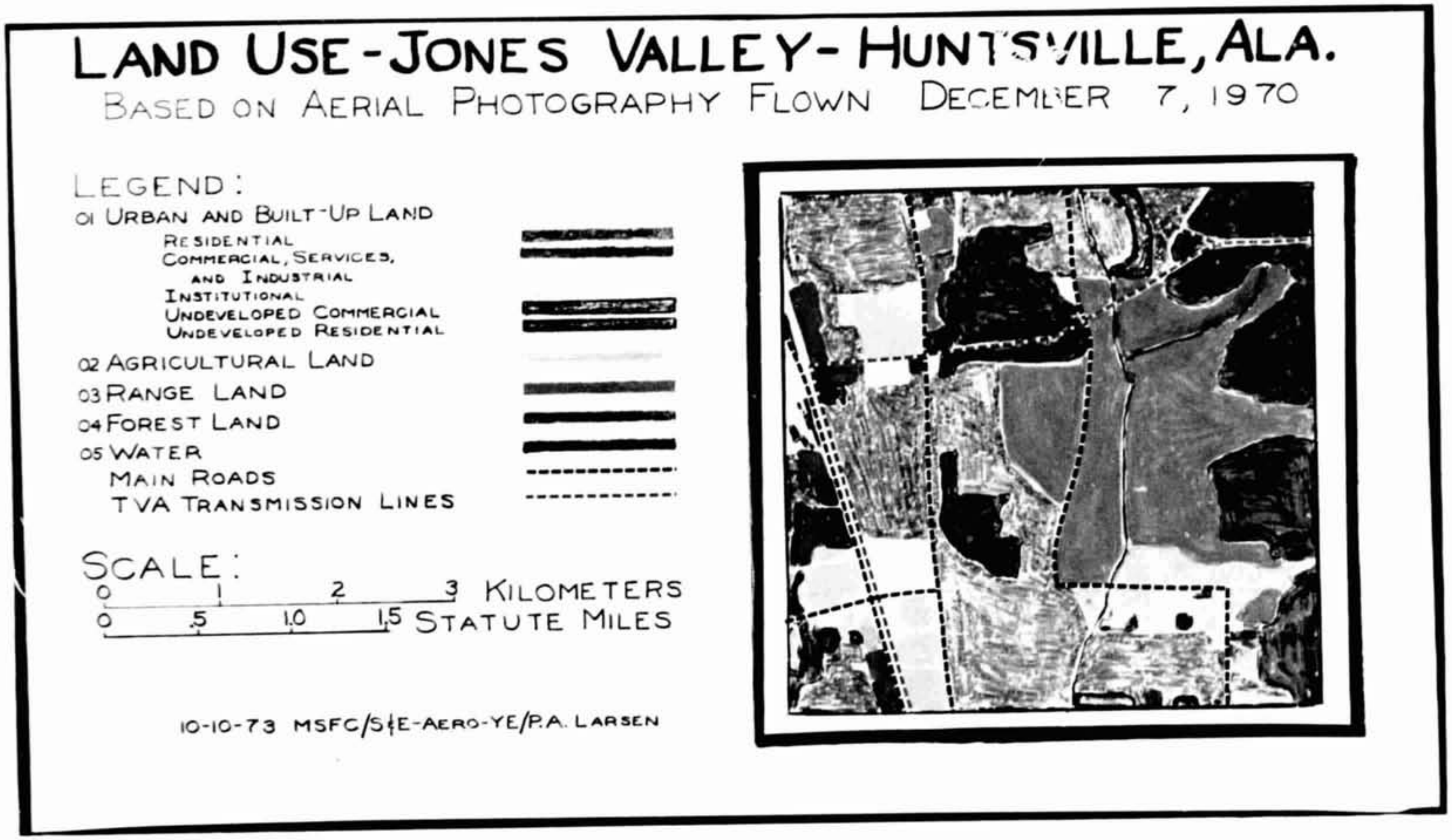


Figure 4. Land use – Jones Valley, Huntsville, Alabama.

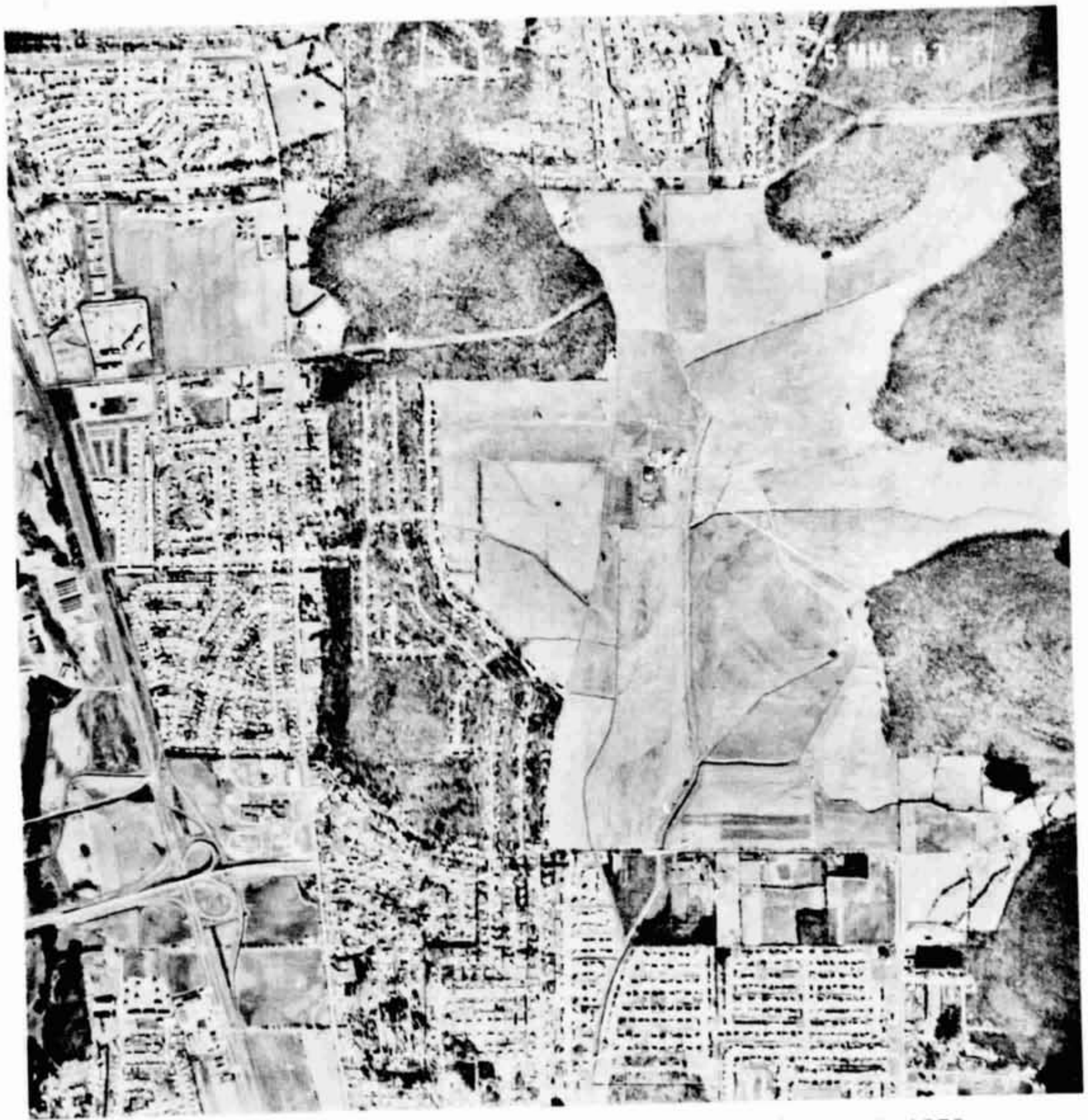


Figure 5. USDA photograph HM-5MM-63, dated December 7, 1970.

same flight line, were utilized. Stereographic pairs of adjacent photographs were combined in such a fashion to enable one to view the imagery three-dimensionally with a simple lens stereoscope. Another reason for choosing this particular frame for study use was because the large range area shown surrounding the Jones Farm, just to the right of center of the photograph, is also quite visible on ERTS-1 imagery (Band 7) of this area.

Most areas of the photograph were easy to assign to appropriate land use categories with the help of a light table and some magnification. In several instances a stereoscopic examination was required to discriminate between agricultural land and rangeland, between commercial zones and institutional areas, and to locate power lines. But, with reasonable effort, these choices could be made without too much difficulty.

One important factor that must be considered when making a land use study of any type, is that current USDA Agricultural Stabilization and Conservation Service (ASCS) imagery is available for most parts of the country. It is a high contrast imagery of good cartographic quality and excellent resolution. It is readily available and quite inexpensive. It can be purchased by anyone from the Eastern Aerial Photography Laboratory in Asheville, North Carolina.

The map shown in Figure 4 was prepared using the Land Use Classification System specified in Geological Survey Circular 671 as its basis. The legend on the map shows the color codes selected for this map for the various types of urban and built-up land, agricultural land, rangeland, forest land, and water. Thus five of the nine "Level I" land use classifications and four "Level II" classifications as specified in Circular 671, were utilized in the preparation of this land use map. The four Level I land use categories which really are not pertinent to the small study area shown, and which therefore were not considered for mapping were nonforested wetland, barren land, tundra, and permanent snow and ice fields.

While preparing this map, undeveloped lands currently not in use, which were adjacent to or within existing commercial areas, were considered to be "undeveloped commercial." These areas were color coded the same color as commercial, but outlined in black. In like manner, residential areas which were not completely developed at the time this imagery was obtained, were color coded residential and outlined in black since they were to be subsequently developed. Main roads were shown with black dashes and TVA transmission lines with red dashes.

This type of "small area and large scale" map is quite helpful to those engaged in activities such as urban expansion studies, farming, cattle grazing enterprises, city government planning, forest resource utilization, real estate marketing, and parks and recreational area planning.

A cursory review of the mapped area shows that approximately 40 percent of the area is residential, 25 percent range, 20 percent forest, and the balance of the area is being used for agricultural, institutional, and other purposes.

As was the case of the small scale map of the land use study area shown in Figure 3, a record of time spent in preparing the map (Fig. 4) from the photograph (Fig. 5) was not kept. However, a realistic estimate of time and materials required would be 10 engineering/photo-interpretation man hours and less than $1.00 in material costs.

As a contrast to the smaller scale land use map of Central North Alabama shown in Figure 3, one can see that the resolution or degree of detail in a large scale map such as that of Jones Valley at a scale of 1:20,240 (scale somewhat reduced in this report) permits the map to reveal a greater amount of information per unit area than does a smaller scale land use map such as that in Figure 3. Both map types have their purposes and both have their limitations. An important consideration relative to the preparation of large scale land use maps of this type is that one can easily prepare a map of his own geographic area of interest, using readily available current imagery and basic engineering tools, which will serve a variety of basic and everday needs, such as those examples mentioned above.

A reproduction of the aerial photograph from which the large scale map was prepared was shown in Figure 5. A cursory examination reveals the large rangeland area on the right, and route US-231 (Memorial Parkway) which runs north-northwest on the west edge. Residential areas appear to the north, west, and south of the range area. Some scattered agricultural areas remain, but are gradually being taken over by residential, commercial, and institutional land users. Forested areas remain, but in some cases these also are falling victim to residential area expansion.

General Comments and Recommendations

While performing the analyses reported herein, generous use was made of the 1:20,000 scale USDA panchromatic imagery for large scale land use map preparation. This was done because the scale of USDA imagery is approximately equal to that of the computer printout resulting from processing of the ERTS multispectral scanner tapes, thereby facilitating direct comparisons of information content. In addition, ERTS prints at a scale of 1:1,000,000 did not provide the resolution nor degree of detail desired in the selected land use study area.

For the synoptic or small scale land use map preparation, RB-57 obtained infrared imagery was used at a scale of $\approx$ 1:144,300.

Conclusions made, based on this section of the reported work, are listed as follows:

1. The 1:144,300 Infrared Aerial Photomosaic contains a greater amount of land use category detail and information than can be efficiently and economically mapped at that scale manually.

2. It does provide, however, a very good Level I mapping base, provided rangeland and agricultural land can be assumed to be lumped into one category for the mapping purpose under consideration.

3. If the original RB-57 infrared imagery positive transparencies were magnified from 1:120,000 scale up to the scale of the sequential classification scheme and spatial and spectral classification scheme printouts (approximately 1:20,000), then the visual land utilization information content of the two would be reasonably similar.

4. The level of detail reported on a 1:20,000 scale land use map, prepared manually from USDA black and white aerial photographs using basic stereoscopic interpretation techniques, compares favorably with the information content provided by a similar scale printout version of either the spatial and spectral or the sequential automated classification schemes.

5. The 1:144,300 scale land use map of central north Alabama, prepared from the infrared aerial photomosaic of the same scale, does not provide the degree of land use component detail that the 1:20,000 scale automated classification scheme prepared map does. However, the variety of applications for land use maps insures the continual use of each type.

6. A large scale map of a small area, devoted to uses such as commercial and neighborhood urban expansion or perhaps truck farms raising small acreage cash crops, could certainly be enhanced by the application of the automated classification schemes, with their inherent ability to define many spectral signatures, if smaller areas (i.e., 50 ft by 50 ft) could be classified. On the other hand, the cheaper, less detailed, manually prepared smaller scale version land use map would serve well in applications such as broad forest area harvest planning, range and farmland expansion studies and hydrological energy resource planning and utilization studies.

7. Land use maps prepared by using conventional photogrammetric engineering techniques and current aerial photography can be compiled directly and quite inexpensively from the imagery in one basic operation; however, updated aerial photography of a scale suitable for land use map preparation becomes available usually only once every 4 to 5 years. Conversely, land use maps prepared by automated computerized land use classification techniques, as discussed in this report, must be prepared using several computer steps or iterations; however, updated digital tapes providing ground scene/land use intelligence become available during the sensor's orbital lifetime for application to land use mapping projects much more frequently than the aforementioned updated aerial photography, thereby facilitating the desirable temporal updating feature more frequently.

COMPUTER LAND USE STUDY OF CENTRAL NORTH ALABAMA

Introduction

Two computer programs developed by members and under sponsorship of the Aerospace Environment Division, Marshall Space Flight Center, are evaluated toward the application of land use mapping. These two programs are called the Composite Sequential Clustering Program (CSCP), [4] and the Spatial and Spectral Clustering Program (SSCP) [5]. Although the two programs are designed to have similar end products, two different approaches are used. The ultimate objectives of both programs were to minimize the requirements of human judgement and intervention in the data analysis loop and to perform the analysis as automatically as possible, because of the potential need for analyzing large volumes of earth observation data. Thus, an attempt was made to perform the analysis with little a priori knowledge of ground truth, and to limit subjective judgement concerning the analysis to the interpretation of the results.

Three distinct advantages can be realized from performing the analysis without prior knowledge of ground truth, and especially in cases where the analysis area is quite large. First, the analysis is performed with a minimum amount of prejudgement. The second advantage is that ground truth patrols can be directed to collect ground truth in a manner which minimizes cost, manpower, and time. Thirdly, the maps resulting from the analysis can also be used as an information base where it is desirable to use considerable human judgement in the analysis or, if required, to improve the accuracy of results.

Although the programs were written with the above mentioned intentions in mind, plenty of restart capabilities and places for supervision of the results were also included. There were several reasons for doing this. More often than not, it is better to be safe than sorry, especially where large amounts of data and computer time are involved. Second, the programs are more flexible; and third, the programs are easily adaptable to interactive processing, where that capability is available. As more experience and confidence are obtained from using these programs, the amount of required supervision can be decreased, but at present the amount of supervision desired is left up to the individual user.

The computer programs were evaluated based upon the required resources and the results obtained. Specific resources that were considered were cost, time, equipment, and human involvement, but the results had to be subjectively evaluated on accuracy and usefulness of information. Although the computer analysis was performed on ERTS digital data, the accuracy comparative analysis was performed with aerial photography at scales of 1:20,000 and 1:144,300. The aerial photography that was available had been acquired during the same month but two years prior to the ERTS data collection. The photography did have the advantage that the needed detail was provided, although some ground scene changes were noted, at a scale more comparable to the computer output.

The main objectives of the computer analysis were to produce a map of at least the Level I land use categories discussed in the photogrammetric section and to determine how well the photogrammetrically derived land use classification scheme agreed with the computer classification scheme. Lower level category information was retained on the computer maps when identification was possible, but no attempt was made to distinguish crop categories because of the ground truth collection requirements.

General Equipment and Data Requirements

The required input data for both programs consists of digital data contained on a magnetic tape with a maximum of 12 allowable channels of data. It is not mandatory to analyze all 12 channels simultaneously, since an option is provided for selecting any combination and number of channels equal to or less than 12. The input data can be acquired from any number of sensors, such as from multispectral photography and/or scanners, as long as the channels of the data set are matched point for point on the ground scene. Then, each point on the ground scene is represented by a spectral vector whose components are the amplitude of the data in the corresponding channels.

Both programs are written in Fortran IV and are currently running on an IBM 7094/44 in a 32K core size environment. Originally, the programs were written in modular form, but the modules have been interfaced because the core storage was available. As a result, the programs require anywhere from 4 to 12 tape drives depending upon which analysis options are exercised. When core storage and tape drives become a constraining factor, the programs can be separated into their original modules and run in sequential order with the output of the previously run module being used as an input to the next module.

At present, the output to both computer programs is limited to standard computer printout, microfilm, and Xerox copy obtained from the microfilm. Typically, all statistical information is limited to the printout, while the maps that are generated are output in all three forms. The maps can then be examined at a variety of scales for imagery comparison. The reader is invited to consult References 6, 7, 8, and 9 for more specific and detailed information.

A set of ERTS (Earth Resources Technology Satellite) imagery and associated bulk MSS (Multispectral Scanner) digital data was obtained for the analysis. The image, ERTS-E-1104-15552, acquired on November 4, 1972, covered an area of approximately 13,000 square kilometers over North Central Alabama. The digital data associated with the image is contained on 4 magnetic tapes with each tape containing 4 spectral channels of data, 2,340 scans/channel, and 810 data samples/scan/channel. The 4 channels of data cover the spectral ranges 0.5-0.6, 0.6-0.7, 0.7-0.8, and 0.8-1.1 micrometers.

Spatial and Spectral Clustering Program (SSCP)

THOUGHT PROCESS USED IN DEVELOPING THE PROGRAM

The program was originally developed with aircraft scanner data in mind, which meant that the data would probably be acquired in one long continuous strip. The objective was to develop a program which could analyze the data, with minimum supervision and without a priori knowledge of ground truth, and output spectral signatures and a map showing the location of all the different unidentified spectral features. The identification of the various features would then be accomplished by collecting the appropriate ground truth.

As a model for the development process, an attempt was made to determine how a human observer would analyze the data, given an unlimited amount of time and resources, and then try to write this procedure down in terms of a computer language and mathematics. Since the end product of the analysis was to be a map showing the geographic location of spectrally different features, this suggested looking for changes in the data where the ground scene changed from one feature to another. Ideally, one would like to be able to draw a map of the data set showing regions occupied by a particular feature, similar to what a photo-interpreter does when he produces a land use map from a photographic image. These two ideas suggested the use of a contour or grey level program or a boundary program. The contour or grey level programs were ruled out because they only operate on one channel of data at a time, and when many data channels are used, it is expedient and desirable to produce one map from all data channels simultaneously. Two boundary mapping programs were developed and they are discussed in detail in the Boundary Map section. One of the difficulties encountered in producing a boundary map was the problem of not being able to completely surround a particular feature with a closed boundary, and this produced problems for the next stage in the analysis procedure. This problem is due to the varying degrees of changes that are present within the data, and sometimes these changes, within an apparently homogeneous area, are as large as changes that exist between different spectral features that are geographically adjacent. Thus, a tradeoff usually exists between choosing a boundary map which completely surrounds every feature, but on the other hand does not produce so many boundaries as to render the map useless.

Assuming that a reasonable boundary map of the ground scene can be produced, the next step is to determine a way of fetching the data from each homogeneous area without mixing the data with a spectrally different feature. Since there are boundaries that do not completely surround a feature, the possibility of fetching data simultaneously from two spectrally different features exists. The method adopted for fetching the data from the homogeneous areas is explained in detail in the section covering spatial clustering. The procedures described thus far have concentrated on the geographical aspects of the data rather than the spectral aspects, and as a result, there has been a considerable reduction in the amount of data to be handled and examined. The boundary

map has reduced the original number of data channels down to one, and the spatial clustering is performed only on the one channel boundary map and only in homogeneous areas of a minimum size. The output of this section of the program is a boundary map that contains the location of the spatial clusters, or the cluster map.

The next step is to examine the spectral information associated with each spatial cluster to determine how many different spectral features are obtained and which features are spectrally similar. This is accomplished by inputting the cluster map and the raw data into the spectral merging routine. Again, not all of the raw data is examined, but only the data contained within the geographic location of the spatial clusters. Data from different geographic areas are combined or merged, if the areas represent spectrally similar features, until finally a finite number of spectrally different features or classes remain. The decision logic for combining or merging data from differing geographic areas is also discussed in the section covering spectral merging.

In order to produce a computer classification map, it is now necessary to check each data point to determine whether or not it belongs to one of the remaining spectrally distinct features. The decision logic is discussed in the section covering classification.

For additional background information and computer program listings the reader is invited to consult References 5, 10, and 11. The Analysis Procedure Section contains information that is somewhat repetitive of References 5, 10, and 11, but it is repeated to provide continuity and visibility to the data analysis procedure. The next section however, was written with added detail and does contain new changes that were made in the programming logic.

ANALYSIS PROCEDURE

Boundary Maps

Because core storage is limited, SSCP was written to handle a maximum of 255 samples/scan/channel for a total of 12 channels of data. As a result of this constraint, an ERTS tape is analyzed in 4 separate strips, where 3 of the strips contain 202 samples/scan/channel and the 4th strip contains 204 samples/scan/channel.

The basic objective of the boundary program is to categorize the digital data representing the ground scene into homogeneous and nonhomogeneous areas. This is accomplished by comparing the spectral vector of a particular point in the ground scene with the spectral vector of the adjacent point in the same data scan and with the spectral vector of the adjacent point in the same data column. The program has to be able to detect changes in the north-south direction of the data set as well as in the east-west direction. This not only indicates spatial continuity within a scan line but also across scan lines. If there is a significant difference between the spectral vector of the particular ground scene point in question and the spectral vectors of the adjacent ground scene points, then there must also be a significant spectral difference in what is being observed

in the ground scene. Thus, a large amount of change in adjacent data points is indicative of when the ground scene is changing from one particular feature to a spectrally different feature. A measure of this change that is used is a calculation proportional to the euclidian vector distance, where the dimension of the vector space is equal to N, the number of data channels. In mathematical terms, let ${}_kx_{i,j}$ be the amplitude of the data in channel k at scan i and column j. Then, the change in the data in the scan direction is given by

$$S_i = \left\{ \frac{1}{N} \sum_{k=1}^{N} ({}_kx_{i,j} - {}_kx_{i,j-1})^2 \right\}^{1/2} , \quad (1)$$

and the change in the column direction is given by

$$S_j = \left\{ \frac{1}{N} \sum_{k=1}^{N} ({}_kx_{i,j} - {}_kx_{i-1,j})^2 \right\}^{1/2} . \quad (2)$$

The factor N^{-1} is used to minimize the effect of S_i and S_j increasing as the number of channels increase when different data sets are used. This is an important consideration since unscaled distributions of S_i and S_j may vary considerably with the number of channels and data set, and only a fixed amount of core storage can be allocated for the distributions.

The boundary program used in the analysis, called the Sequential Boundary Program, considers two consecutive scans of data at a time, scan i and scan i-1. For these two scans, distributions of S_i and S_j are computed using integer class intervals, and both distributions are divided into seven categories. These categories are determined by finding six increasing values of S_i ($S_{i1}, S_{i2},\ldots,S_{i6}$) and six increasing values of S_j ($S_{j1}, S_{j2},\ldots,S_{j6}$) such that 59 percent of the data points in scan i have values of S_i and S_j equal to or less than S_{i1} and S_{j1}, 64 percent have values less than or equal to S_{i2} and S_{j2}, 69 percent have values less than or equal to S_{i3} and S_{j3}, 74 percent have values equal to or less than S_{i4} and S_{j4}, 79 percent have values less than or equal to S_{i5} and S_{j5}, and 89 percent have values equal to or less than S_{i6} and S_{j6}. In order to determine whether or not a given data point is a boundary point, the values of S_i and S_j are examined for each individual data point in scan i. If S_i is greater than S_j, then the S_i distribution is

consulted for that particular data point, otherwise the distribution for S_j is consulted. Based upon which distribution was consulted, the data point is labeled according to which category the larger of the two values, S_i or S_j belongs. The possible labels for each data point are the integers 0, 1, 2, ..., 6, where 0 represents the 59 percent level or less, 6 the 64 percent level or less, 5 the 69 percent level or less, 4 the 74 percent level or less, 3 the 79 percent level or less, 2 the 89 percent level or less, and 1 represents greater than the 89 percent level. A map of the ground scene is then produced on digital tape that only contains the integers 0 through 6, and the program user now has the option of choosing which categories will produce boundary points and which will not. The parameter in the program which determined the boundary map is the variable NLEVEL. Based upon previous experience with several different data sets, NLEVEL is typically set to 4, although it has an allowable range of from 1 to 6. If NLEVEL is set to 4, then non-zero values on the map equal to or less than 4 are defined to be boundary points. Another tape for printing or for microfilm is produced containing a map showing the location of boundary points only.

There are several assumptions in the above programming logic that are slightly hidden and worthwhile to explore. The first assumption is that the number of boundary points per scan is almost a fixed percentage. By setting NLEVEL equal to 4, for example, means that approximately 34 percent of the data per scan will end up being boundary points. There could be a lesser percentage of boundary points if many cases were encountered where, say, S_i is greater than S_j and S_i is not indicative of a boundary point but S_j is, or vice-versa. There also could be a larger percentage of boundary points, which is usually the case, because the S_i's that are indicative of boundary points do not always occur simultaneously with S_j's that are indicative of boundary points, and vice-versa. The third possibility is that the population contained in the different levels probably will not occur in exactly 5- or 10-percent increments, i.e., one level may have approximately 5 percent while the next level may only contain 4 percent.

From an aesthetic point of view, the idea of a fixed number of boundary points per scan may not be pleasing, but the logic has its advantages. One advantage is that the program runs fairly fast and only requires one pass through the raw data. The second point is that the boundaries are determined from conditions contained in a small local area rather than from the overall conditions of the entire data set. One disadvantage of using local information for determining boundaries occurs when scattered clouds are present in the data. The clouds tend to absorb all of the boundary points, because of their inhomogeneity, and no patterns can be delineated in the ground scene.

If clouds do present a problem in the data, an alternate boundary program, called the Joint Boundary Program, can be used. As the name implies, the program computes the joint distribition of S_i and S_j, but for the entire data set, and requires one pass through the raw data tape and another pass through an intermediate tape. The joint distribution is calculated in integer class intervals using equations (1) and (2), and is

limited to a 50 by 50 array. From past experience the array was found to be large enough so that any data point with a value of S_i or S_j larger than 50 could be automatically defined as a boundary point for practically any data set. As the raw data are read into the program and the number of occurrences of S_i and S_j combinations are accumulated in the joint histogram, a new tape is created for later use. This tape contains the integers 1 through $50^2 = 2{,}500$ and instead of writing S_i and S_j on this tape for each data point, one number is written on the tape that gives the location of S_i and S_j in the joint histogram. The location, I, of S_i and S_j in the joint histogram is computer using

$$I = (51)\, S_i + S_j \quad , \tag{3}$$

and is a unique one-dimensional representation of the two dimensions S_i and S_j. The new tape containing an integer I for each data point eliminates the necessity for recalculating S_i and S_j for each data point a second time. After all the data elements from the data sets have been exhausted and the joint distribution is complete, a decision is made as to which combinations of S_i and S_j are to be considered as boundaries. The decision curve for a boundary point is based upon the formula

$$\left(\frac{S_i}{S_i' + \mathrm{ASCN}}\right)^{\mathrm{IPOW}} + \left(\frac{S_j}{S_j' + \mathrm{ACOL}}\right)^{\mathrm{IPOW}} > (2)\mathrm{BLIM} \quad , \tag{4}$$

where S_i' and S_j' are the values of S_i and S_j at the mode of the joint histogram and ASCN, ACOL, IPOW, and BLIM are input parameters to the program. The input parameters allow for a wide variety of decision curve shapes and positions. Nominally IPOW = 2 and BLIM = 1, where as ASCN is usually equal to ACOL and must be estimated based upon experience. The possible values of I, or correspondingly S_i and S_j, are then inserted into equation (4) and the variable N(I) in the computer program is set equal to 0 if equation (4) is not satisfied and is set equal to -1 if equation (4) is satisfied. The tape containing I for each data point is then read into the program, and the value of N(I) is written out as another tape that contains only the integers 0 and -1, with -1 representing a boundary point. The Joint Boundary Program runs slightly longer than the Sequential Boundary Progra n, because of the use of an intermediate tape. Both programs use alphanumeric characters to convert the integer tapes to paper or microfilm maps. For example, the alphanumeric symbol for a zero is usually a blank, while the symbol for a -1 is usually a period representing a boundary point.

A boundary map from the Sequential Boundary Program of the North Central Alabama test site is shown in Figure 6. The map covers 3 ERTS tapes of image ERTS-E-1104-15552, which have been divided into a total of 12 strips, and is 1,300 scans by 2,430 samples/scan. The brightest area in the map is the Tennessee River, since the data representing the water present very little change within the river, except at the river edge. The other large areas that appear homogeneous are mostly uniformly forest covered areas.

A color composite of the ERTS imagery corresponding, to the boundary map, is shown in Figure 7 for comparison. The color composite was made by illuminating 3 of the 4 ERTS image bands with red, green, and blue light, and hand registering the resulting images on a color composite camera system. The image was then photographed to obtain a negative from which a print could be made. Typically, all of the photographic products presented in the computer section show varying amounts of degradation due to number of photographic reproductions required for producing the report figures. Compare Figures 6 and 7 with Figures 2 and 3 also.

Examination of the boundary maps provide several types of information. First of all, the boundary map provides a simultaneous check on the condition of the data in all channels. Bad places in the data tend to show up conspicuously. Secondly, the boundary map provides a means of correlating the location (scan and column) of the data on the digital tape with particular geographic areas in a photographic image or another map. This information can then be used to select appropriately scaled aerial photography for ground truth comparison. Different features in the ground scene will appear on the map with varying degrees of homogeneity. By comparing the size and homogeneity of the areas occupied by particular features with aerial photography, some indication can be obtained for determining the types of information that can be retrieved from the data set. Also, this type of examination can be useful for manually selecting particular training areas when it is desirable to produce a map of only a few specific features for a particular application. Finally, the boundary map is examined from a quality point of view and compared with imagery to see whether there are enough boundary points to properly delineate homogeneous areas in the ground scene or whether the map contains too many boundary points. As a general rule of thumb, experience has indicated that approximately 34 percent of the data points in a data set should be boundary points. Table 1 gives the exact percentages of boundary points for each strip.

The next step in the procedure was to select one of the twelve strips for further analysis. This strip was selected on the basis of whether or not it contained a majority of the Level I category land use classes, which were urban and built-up land, agricultural land, rangeland, forest land, water, non-forested wetland, and barren land. Tape 3, strip 2 seemed to satisfy most of these requirements, and the boundary map from that strip was input into the Spatial Clustering Program.

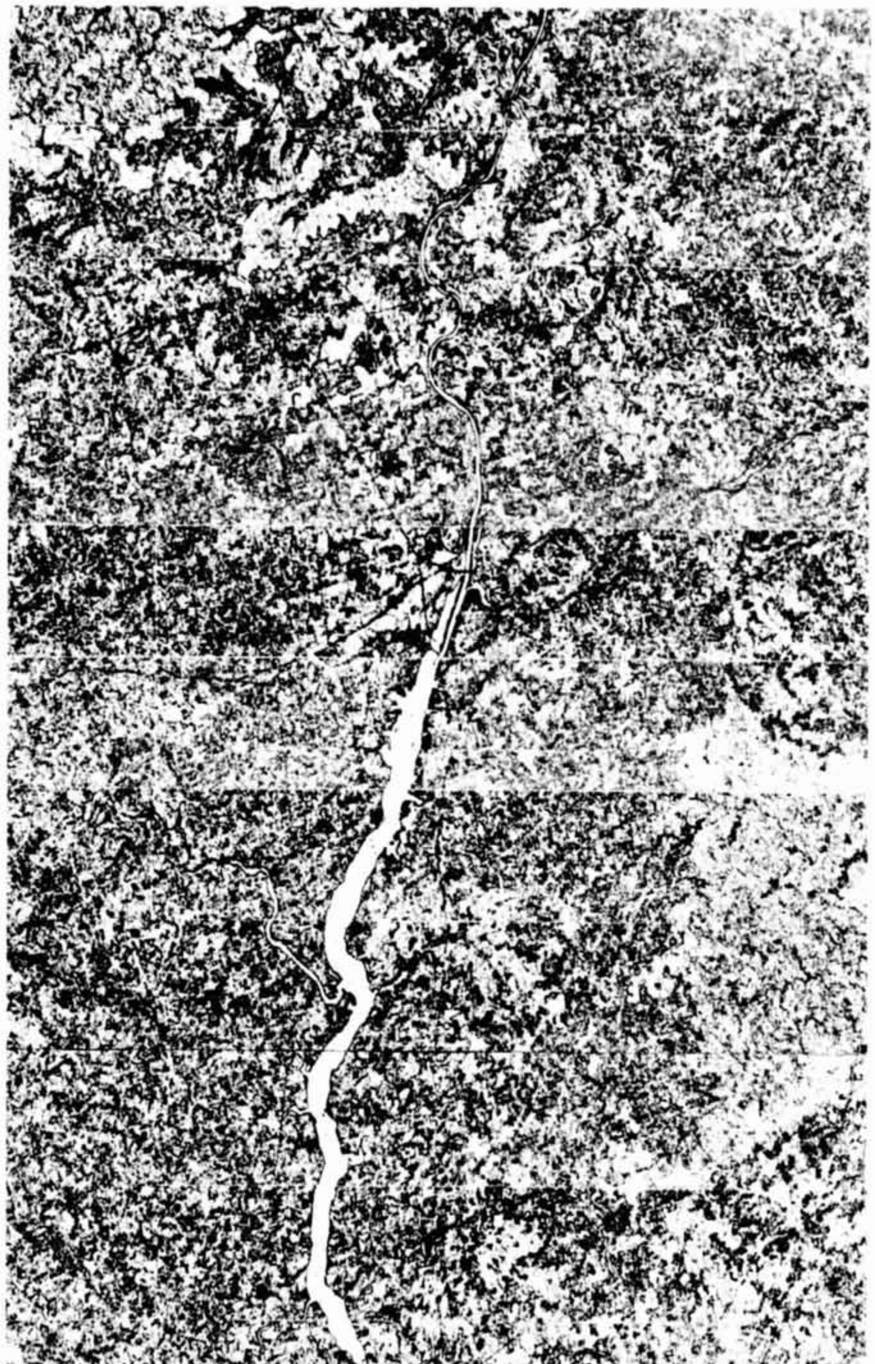


Figure 6. Boundary map of Central North Alabama study area.

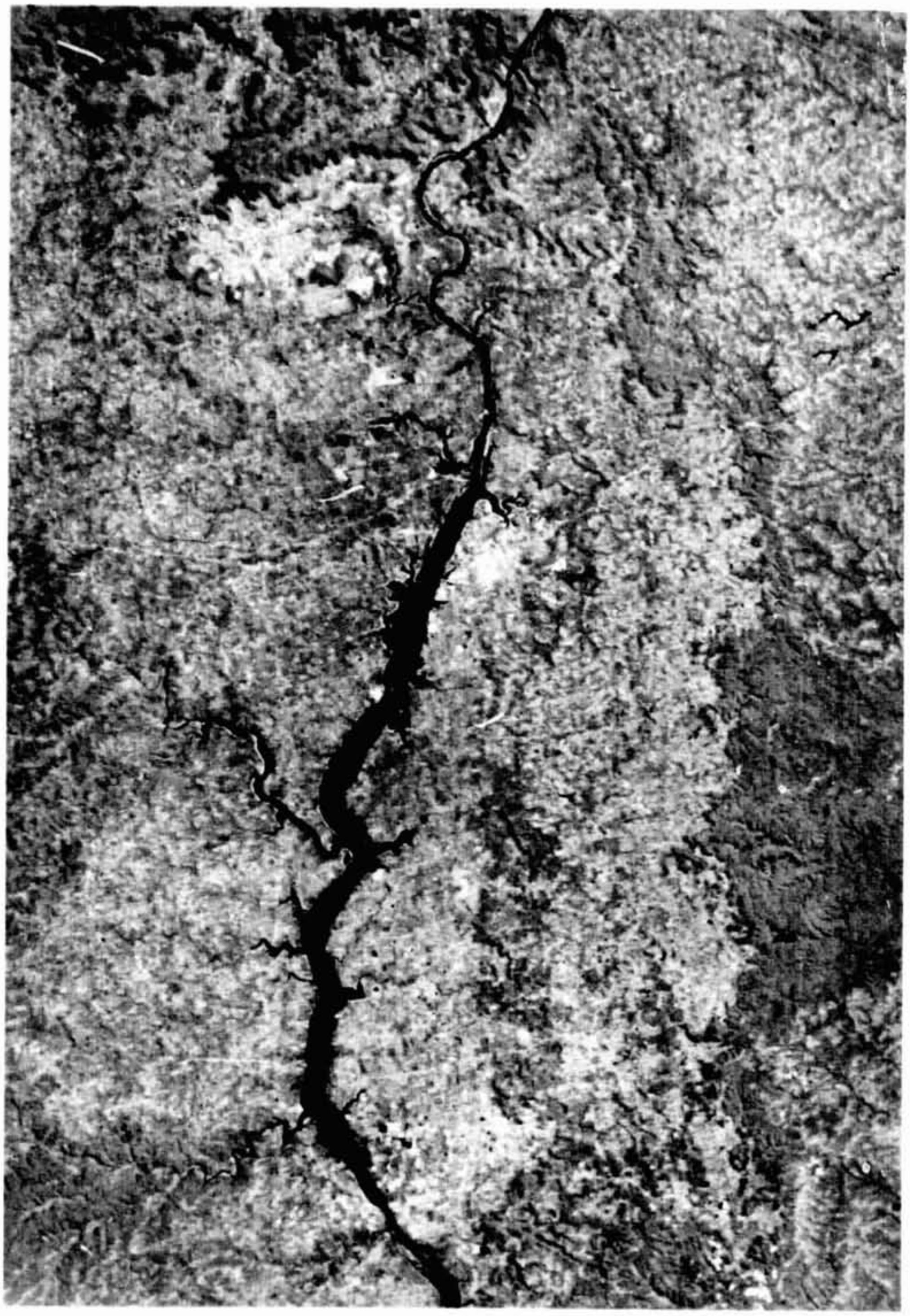


Figure 7. ERTS color composite of land use study area.

TABLE 1. PERCENTAGE OF BOUNDARY POINTS FOR EACH DATA STRIP USING SEQUENTIAL BOUNDARY PROGRAM WITH NLEVEL = 4

Tape	1				2				3			
Strip	1	2	3	4	1	2	3	4	1	2	3	4
% Boundaries	33.51	34.02	34.51	34.65	34.13	33.87	34.18	34.93	35.10	34.64	34.10	32.47

Spatial Clustering

The Spatial Clustering Program, discussed in this section, and the Spectral Merging Classification Programs, discussed in the next two sections, are all part of what is called the Composite Classification Program. The three programs are discussed separately because their functions are different. The spatial clustering segment of the composite program can accept a boundary tape from either the Sequential or Joint Boundary Program. In either case a boundary point is mathematically represented by -1 in the program and non-boundaries by 0's. The purpose of the spatial clustering program is to locate and label homogeneous areas of a minimum size or larger contained within a boundary. Hopefully, this is done in such a way that a labeled area does not contain data representing a combination of two spectrally different features. This is accomplished by using a fixed shaped p by p data point array which moves through the boundary map only in the scan or column direction. Initially, a homogeneous area in the boundary map is found which is large enough for the array to fit into. The area covered by the array is designated as belonging to cluster 1, and the array is allowed to move in this area until a boundary point is encountered and then the array can no longer move in that direction. All data point locations falling within the movement of the array are said to belong to cluster 1. As the boundary tape is read into the spatial cluster program, a cluster tape is written out which contains 0's and -1's as on the boundary tape, but in addition, the data locations that were previously 0, but now belong to cluster 1, are written out as 1's on the cluster tape. After the array can no longer move and engulf new data point locations, another location is found which will contain the p by p array. All the data point locations engulfed by the array will be designated as belonging to cluster 2, and the corresponding 0's on the boundary tape will be converted to 2's on the cluster tape. This process is continued until all the boundary map data have been exhausted. Occasionally, two differently numbered clusters were run together. When this occurs, and the two clusters overlap by 4 or more scans, they are spatially merged and designated as the same cluster. After the spatial merging, and in order to keep the bookkeeping straight, the clusters are renumbered so that the cluster numbers will always have a continuous range from 1, ..., N. The output of the spatial clustering program is a cluster tape containing the integers -1, 0, 1, ..., N, which is essentially the same as the boundary tape except that some of the 0's have been changed to non-zero positive integers.

The problem of gathering data from two spectrally different features, because of the gaps in the boundary between the two features, can be eliminated if the p by p array is chosen large enough. Since the array cannot occupy a data point location that is designated as a boundary, the array will generally be large enough so that it cannot pass through the smaller size gaps in a boundary. Previous experience has indicated that a 10 by 10 array size is adequate, which insures that the minimum population of a cluster will be 100. There does exist, however, a trade-off between the array size and the number of distinct spectral features that can be detected. By using a 10 by 10 array size, it is possible to obtain data from homogeneous areas of a size equal to or greater than 10 by 10 only, and it is possible to completely miss spectrally distinct features contained in

smaller homogeneous areas. If the array is reduced in size, then a greater risk is presented in terms of mixing data from two spectrally distinct features, which may result in an inaccurate classification map. The classification map can be completed later by making a second pass through the data, as explained in another section.

A printout of the cluster tape obtained from tape 3, strip 2 using a 10 by 10 cluster array is shown in Figure 8. In order to show the geographic location of the clusters, the print made from the microfilm had to be reduced to a size where it was impossible to read the computer symbols on the map. As a result, the cluster numbers have been labeled to the side of the map. Enlarged portions of the cluster map will be shown in the next section. Examination of the cluster map reveals that it would not be possible to completely classify all of the data. For example, there are no clusters in the Tennessee River representing water. Table 2 lists the cluster numbers and their populations.

Spectral Merging

Until now the majority of the information considered was concerned with the spatial or geographic description of the data. The spectral merging program is the first segment of the composite classification program that is specifically concerned with spectral information and uses the raw data and cluster tapes as inputs. The program uses the cluster tape to locate the raw data belonging to each cluster by skipping through the cluster tape, and correspondingly through the raw data tape, until the integer 1 occurs. Then, for all the data belonging to cluster 1, mean values for each data channel, covariance matrix, eigenvalues, and eigenvectors are calculated. When all the data has been exhausted for cluster 1, the program skips on the cluster tape, and correspondingly on the raw data tape, until a cluster of 2's are found. Statistics are then calculated from the data belonging to cluster 2.

The program has now reached a stage where it is possible to compare the statistics of two clusters and, based upon the decision logic, decide whether or not the two clusters contain spectrally similar information, which means that both clusters represent spectrally similar ground scene features. Although the mathematics of the decision logic is described in detail in Reference 11, it appears helpful to repeat some of it here. Basically, it was desirable to surround the data belonging to a cluster with an n-dimensional cloud surface, so that the region occupied by the data in the n-dimensional vector space would be bounded. The calculation of the mean values, or first order moments, for each channel would determine the location of the closed surface in the vector space, which meant that the shape of the closed surface had to be described by second or higher order moments. In order to minimize the number of moment computations, only second order moments, the covariance matrix, were used and the resulting closed surface was an n-dimensional hyperellipse. The ellipse equation for each cluster was computed in the principal axis coordinate system of the data belonging to that cluster using the eigenvalues and eigenvector matrix, which was obtained from the covariance matrix. The decision rule for deciding whether or not two clusters are spectrally similar is that the data from both clusters are spectrally similar if the mean vectors for

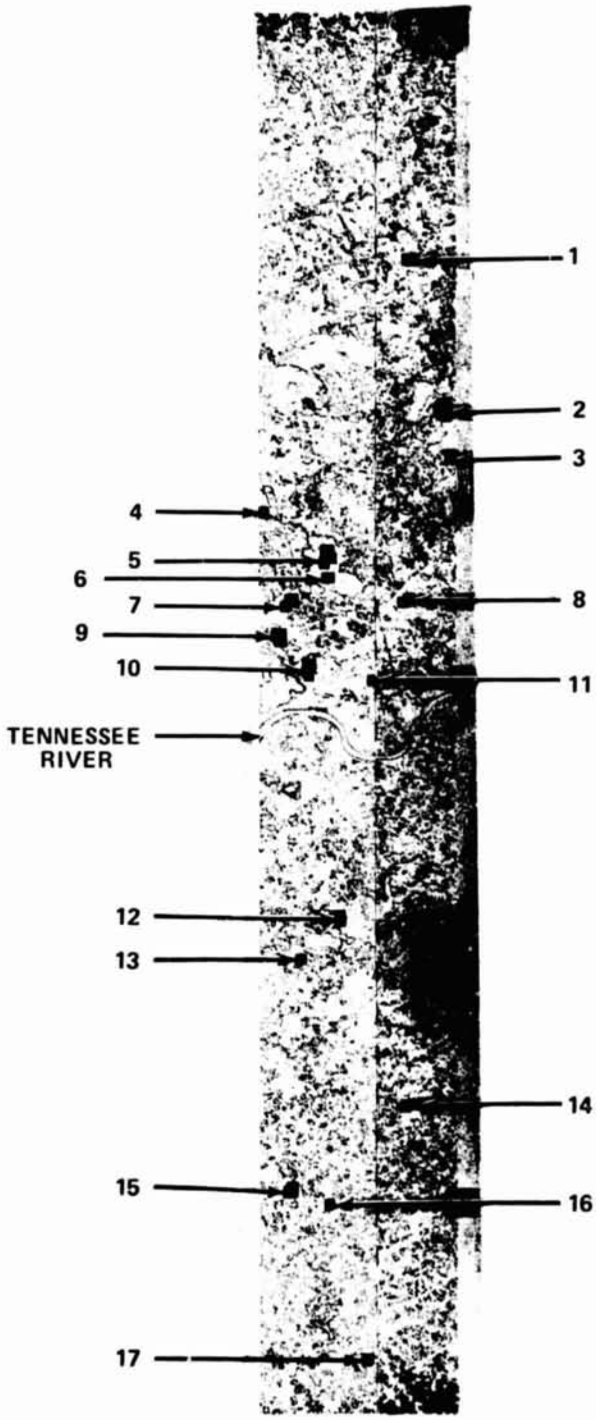


Figure 8. Cluster map using 10 by 10 array on tape 3, strip 2.

each cluster are contained within the ellipse of the other cluster. Mathematically, the decision is made by computing the vector adjoining the center of masses of the two clusters

$$[{}_k\bar{x}_1 - {}_\ell\bar{x}_1, {}_k\bar{x}_2 - {}_\ell\bar{x}_2, {}_k\bar{x}_3 - {}_\ell\bar{x}_3, {}_k\bar{x}_4 - {}_\ell\bar{x}_4] = [Z_1, Z_2, Z_3, Z_4] \quad , \tag{5}$$

where k and ℓ stand for cluster k and ℓ, respectively, and the bars represent the average of the data channels 1, 2, 3, and 4. This vector is transformed into the principal axis system of both clusters via the eigenvector matrix to produce the vector

$$[{}_kZ_1', {}_kZ_2', {}_kZ_3', {}_kZ_4'] \tag{6}$$

in cluster k's coordinate system, and to produce the vector

$$[{}_\ell Z_1', {}_\ell Z_1', {}_\ell Z_3', {}_\ell Z_4'] \tag{7}$$

in cluster ℓ's coordinate system. Finally, the vectors must satisfy

TABLE 2. CLUSTER NUMBER AND POPULATION FOR 10 by 10 ARRAY ON TAPE 3, STRIP 2

Cluster	Population
1	187
2	340
3	153
4	110
5	310
6	130
7	243
8	180
9	242
10	232
11	100
12	150
13	110
14	202
15	294
16	100
17	140

$$\sum_{i=1}^{N} \left(\frac{{}_kZ_i'}{{}_k\sigma_i}\right)^2 < N(\mathrm{SCLMRG}) \quad \text{and} \quad \sum_{i=1}^{N} \left(\frac{{}_\ell Z_i'}{{}_\ell\sigma_i}\right)^2 < N(\mathrm{SCLMRG}) \quad , \tag{8}$$

where ${}_k\sigma_i^2$ and ${}_\ell\sigma_i^2$ are the eigenvalues for the eigenvectors in cluster k and ℓ's principal axis coordinate system, respectively, N = 4 is the number of channels and SCLMRG (scale merge) is an input parameter into the program. Nominally, the product of N and

SCLMRG is equal to one. If equation (8) is satisfied, then the data from both clusters are combined and a new set of mean vectors, covariance matrix, eigenvalues, and eigenvectors are calculated, and cluster 1 and 2 are said to represent a ground scene feature belonging to class 1. If equation (8) is not satisfied, then cluster 1 is said to represent class 1 and cluster 2 is said to represent class 2. All of the clusters are examined in the above manner and checked to see if they will merge with any of the previous classes. The final result is that there will be a finite set of statistics output on a tape, called the statistics tape, which represent the classes of distinct features found in the ground scene. The number of classes can equal the number of clusters, but usually the number of classes is less than the number of clusters due to spectral merging. The statistics that are saved on the statistics tape are the mean vectors, the eigenvalues, and the eigenvector rotation matrix for each class.

Table 3 shows the class assignment for each cluster along with the original mean vectors of each cluster. In order to check the merging procedure and for assistance in interpreting the results, it is helpful to plot a scatter diagram of the mean vector components. This is accomplished in Figures 9, 10, and 11 by plotting the mean amplitude of the data in channel 1 versus the mean amplitude of the data in channels 2, 3, and 4. The location of the cluster mean vector components in the scatter diagram are labeled with the corresponding class number. Figure 12 is a section of the cluster tape printout which shows the geographic location of clusters 4 through 11 with the boundary points represented by dots and clusters represented by the symbols 4, 5, 6, 7, 8, 9, 0, A, respectively. Only 45 symbols are used for representing the clusters and in the event that more than 45 clusters are encountered, the symbols are recycled, i.e., cluster 46 is represented by a 1, cluster 47 by a 2, etc. Figure 13 is an enlargement of a portion of an aerial photograph of the same approximate area, which is used for corroborating the computer printout with the ground truth. Table 4 is a listing of the mean vector components associated with the classes that were obtained by merging. Since the end product that will be used is the classification map, the interpretation of the results is best accomplished by comparing both the cluster map and the classification map with the available ground truth. This is done in the next section.

Classification, Using Composite Program

The inputs to this section of the composite program are the raw data tape, boundary tape, and statistics tape, while the outputs are the classification map and area percentages of classification. The number of classes are limited to a total of 43, because of storage requirements and the fact the map looks quite busy with that many classes. This limit is also maintained in the spectral merge program. Once 43 classes are obtained in the spectral merge program, the program stops searching for new clusters and the classification subroutine is called. The spectral merge program is also limited to a total of 400 clusters, but that limit has yet to be reached.

TABLE 3. CLUSTER MEAN VECTORS AND CLASS ASSIGNMENT

Cluster	Class	Cluster Mean Vector			
		Channel 1 0.5–0.6 µm	Channel 2 0.6–0.7 µm	Channel 3 0.7–0.8 µm	Channel 4 0.8–1.1 µm
1	1	20.273	17.872	21.711	11.15
2	2	18.374	13.365	20.347	11.818
3	2	18.092	13.118	19.412	11.144
4	3	20.882	17.527	19.955	10.9
5	4	18.897	14.8	22.268	13.194
6	2	18.346	13.123	19.762	11.438
7	5	18.181	11.724	20.091	10.984
8	6	19.117	13.906	18.75	10.633
9	4	19.07	14.756	21.264	12.521
10	4	19.341	15.336	21.754	12.681
11	4	14.1	14.94	22.33	13.03
12	2	18.393	13.28	20.427	11.887
13	4	19.327	14.818	23.264	13.455
14	7	17.995	12.747	21.342	12.767
15	7	17.938	11.768	22.701	13.582
16	7	17.84	12.32	21.2	12.68
17	7	17.857	12.186	21.129	12.693

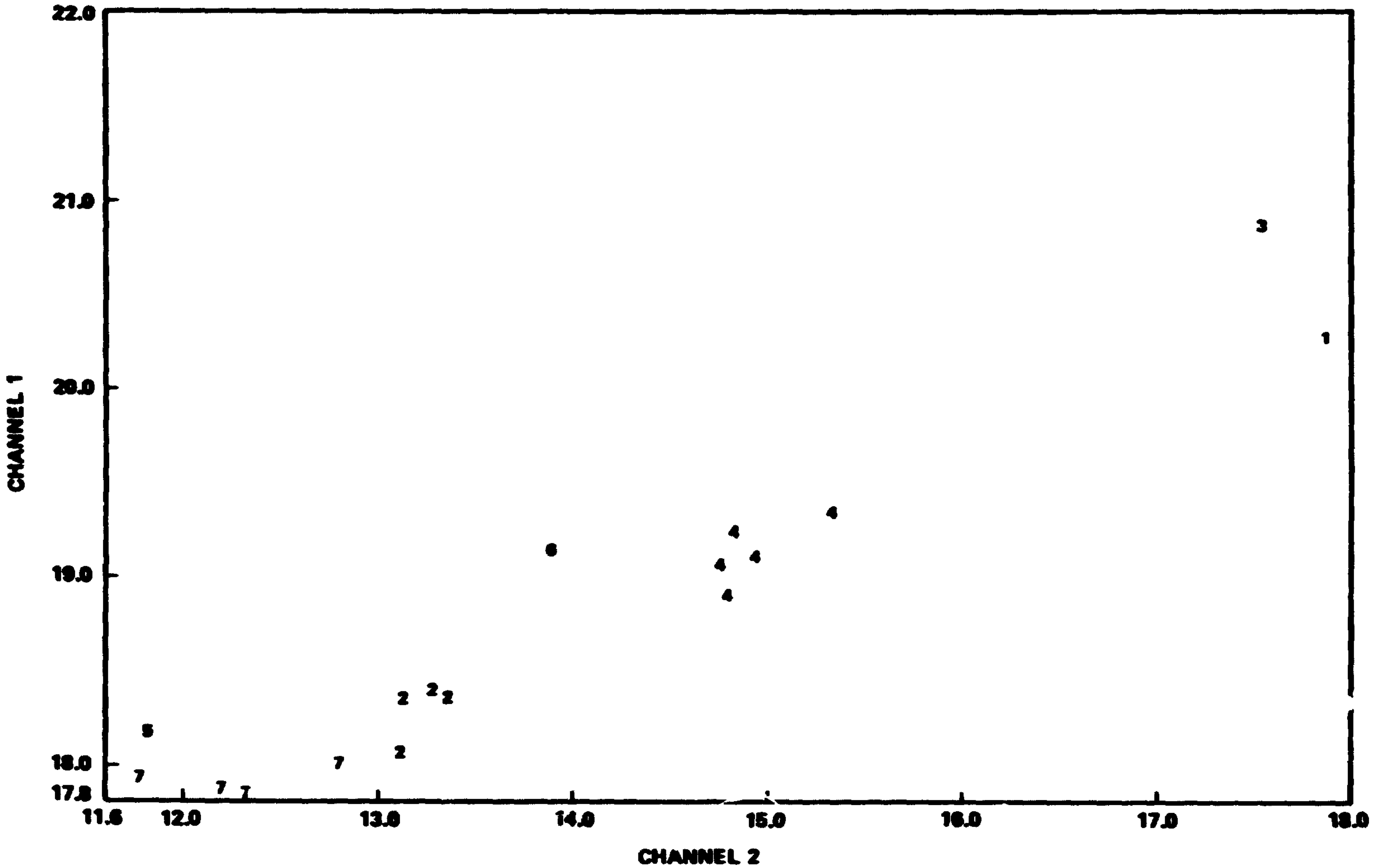


Figure 9. Channel 1 and 2 cluster mean vector components.

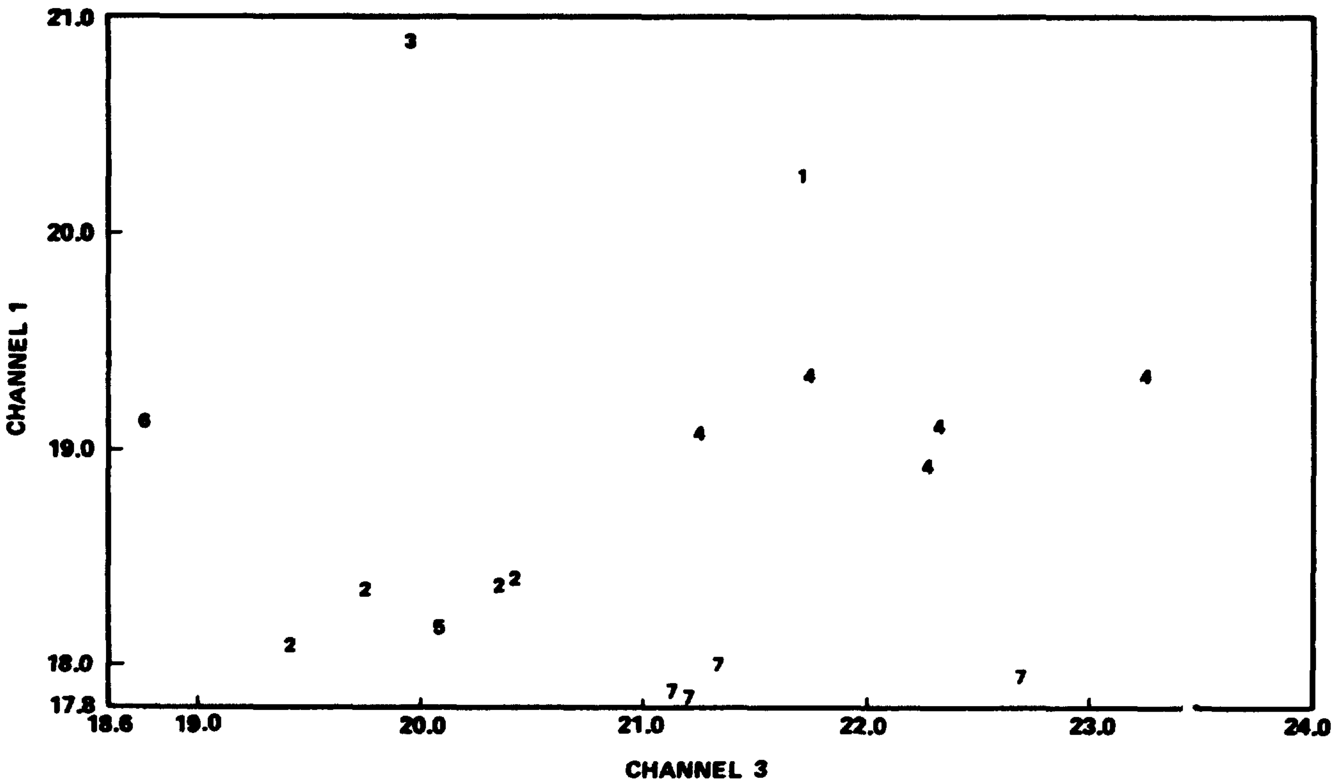


Figure 10. Channel 1 and 3 cluster mean vector components.

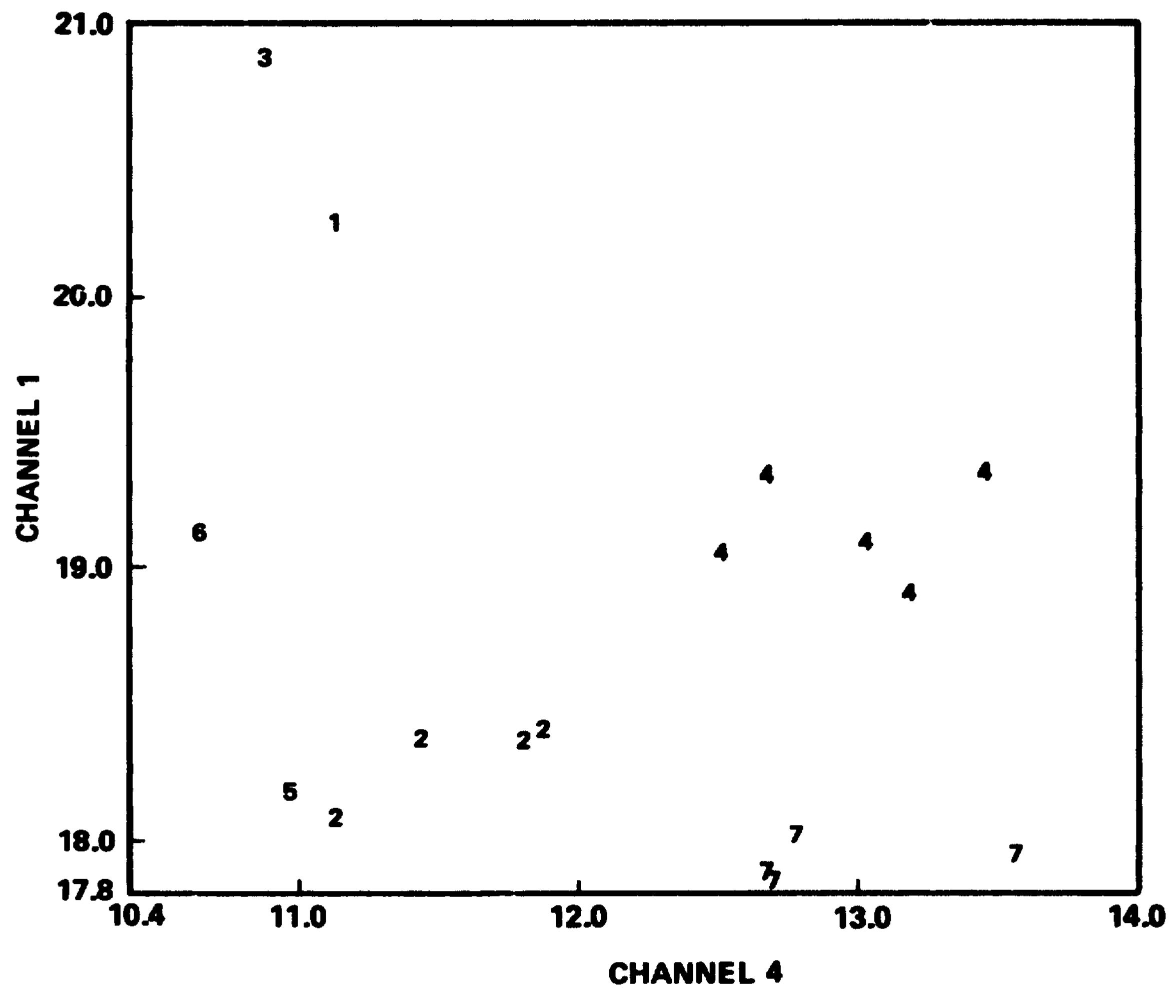


Figure 11. Channel 1 and 4 cluster mean vector components.

Figure 12. Cluster tape output.

Figure 13. Aerial photograph corresponding tc cluster tape output.

TABLE 4. CLASS MEAN VECTOR COMPONENTS

Class	Channel 1	Channel 2	Channel 3	Channel 4
1	20.273	17.872	21.711	11.15
2	18.317	13.259	20.079	11.634
3	20.882	17.527	19.955	10.9
4	19.111	14.931	22.108	12.923
5	18.181	11.724	20.091	10.984
6	19.117	13.906	18.75	10.633
7	17.923	12.274	21.687	12.986

The mean vectors, eigenvalues, and eigenvectors for each class are read and stored in the classification program, and the boundary tape is read simultaneously with the raw data tape. In order to save time and to preserve the boundaries for additional clustering, the boundary points and the raw data corresponding to the location of the boundary points are skipped. Thus, classification is attempted only for non-boundary data points, which typically represent about 66 percent of the data set. It also appears that the majority of misclassifications occur with boundary points, which is probably due to the fact that boundaries represent data that are in the process of changing from one feature to another. During this change, the data could become very much like the data belonging to any feature in the data set. The output classification map with then contain the original boundaries plus the classified data points. Physically, the classification tape will contain the integers -1, 0, 1, 2, ..., N, where -1 represents a boundary, 0 represents an unclassified data point, and 1 through N represent data points belonging to class 1 through N, respectively.

The decision rule for classifying a data point is almost identical to that used for spectral merging. The vector connecting the vector data point in question and class mean vector in question is computed as shown below,

$$[x_1 - {}_k\bar{x}_1, x_2 - {}_k\bar{x}_2, x_3 - {}_k\bar{x}_3, x_4 - {}_k\bar{x}_4] = [W_1, W_2, W_3, W_4] , \qquad (9)$$

where x_1, x_2, x_3, x_4 are the vector components, or channel amplitude of the data point, and ${}_k\bar{x}_1$, ${}_k\bar{x}_2$, ${}_k\bar{x}_3$, ${}_k\bar{x}_4$ are the mean vector components of class k. The eigenvector matrix then transforms equation (9) into the principal axis coordinate system of class k to produce a vector with components $[W_1', W_2', W_3', W_4']$, and the decision rule for classifying a vector data point is based upon the ellipse equation,

$$\sum_{i=1}^{N} \left(\frac{W_i'}{{}_k\sigma_i} \right)^2 \leq 2N(\mathrm{SCLCLS}) \tag{10}$$

The parameter SCLCLS (scale class) is an input to the program and is typically 2.25, N = 4 is the number of channels, and ${}_k\sigma_i$ is the eigenvalue for the ith channel of the kth class. At first glance, it would appear to be more efficient to compute the ellipse equation for each class and not bother with the principal axis transformation, which has to be computed for each data point for each class. However, a time saving can be realized as the number of data channels increase. For example, if 12 channels of data are used, the ellipse equation will have a total of 78 second order terms to sum, some of which are positive and some of which are negative. By using the principal axis transformation, it is not always necessary to compute all the terms for each data point for each class. In the principal axis coordinate system, and for 12 channels, there are only 12 second order terms to sum for the ellipse equation and each term is positive. However, in order to compute each term in the ellipse equation, it is necessary to use the eigenvector rotation matrix and this requires a sum of 12 second order terms for each term in the ellipse equation. The time saving can be accomplished as follows: Equation (10) has to be computed for all classes everytime an attempt is made to classify a data point. The computation is done by transforming one component of the vector and checking the sum against 2N(SCLCLS). If equation (10) is satisfied, another component is transformed and added to the previous sum, which is again compared with 2N(SCLCLS). If the sum exceeds 2N(SCLCLS) for a particular class before all of the components have been transformed, then there is no need to check the other components. The logic of the program then proceeds to check the other classes for the particular data point in question. If equation (10) is satisfied, then the value of 2N(SCLCLS) is replaced by the value of the sum. Thus, everytime equation (10) is satisfied, the right hand side of equation (10) gets smaller, and fewer components need to be transformed as more classes are checked. This type of logic can be used because all of the terms in equation (10) are positive. An additional time saving can be realized by utilizing the geographical information from previously classified data points and assigning priorities on which classes to check first. The priorities for a particular data point are assigned by checking the status of the data point in the previous column of the same scan and the data point in the previous scan of the same column. If the previously classified data points belong to

the same class, then an attempt is made to put the new data point in the same class. If equation (10) is satisfied, the new data point is put into that class, otherwise all of the other classes have to be checked. If the previously classified data points belong to two different classes, an attempt is made to put the new data point in one of those two classes. If equation (10) is satisfied for only one of the two classes, then the new data point is put in that class. If equation (10) is satisfied for both of the classes, then the new data point is put in the class having the smallest sum for equation (10). If equation (10) is not satisfied, then the other classes have to be checked. In both of the above cases, when it is necessary to check the rest of the classes and when equation (10) is satisfied, the new data point is put in the class having the smallest sum for equation (10). If equation (10) is never satisfied, the new data point is left unclassified. If either or both of the previous data points are a boundary or unclassified, then all of the classes have to be checked.

Figure 14 shows the classification map that was obtained for the 7 classes using a 10 by 10 cluster array, and Table 5 shows the percentage of data points belonging to each category. The light areas on the map indicate the areas that are not classified. These areas are mainly water in the Tennessee River, urban in the city of Huntsville and Redstone Arsenal, and other cropland and cattle grazing areas. An enlarged portion of the classification map corresponding to Figure 13 is shown in Figure 15.

It was anticipated that the classification would probably be incomplete with only one classification pass using a 10 by 10 clustering array, so the composite program was actually set up to do two passes. This is generally done

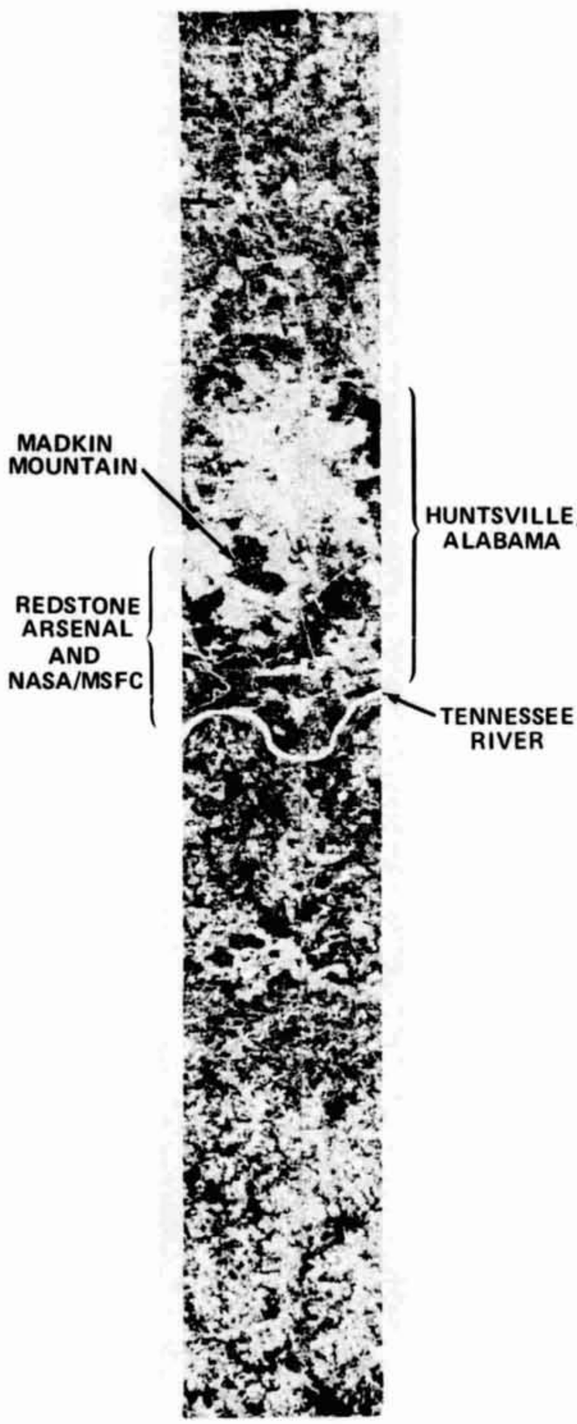


Figure 14. Classification map for 7 classes using 10 by 10 cluster array.

TABLE 5. CLASS POPULATION AND PERCENTAGES

Category	Population	Percentage
Unclassified	63,657	24.76
Boundaries	88,957	34.60
Class 1	15,652	6.09
Class 2	8,837	3.44
Class 3	5,243	2.04
Class 4	33,118	12.88
Class 5	4,790	1.86
Class 6	4,618	1.8
Class 7	32,207	12.53
Total	257,079	100.00

with all computer runs involving clustering. The second pass uses a 5 by 5 cluster array, which gives a minimum cluster population of 25 data points, and instead of using the boundary map again, the clustering is performed on the first pass classification map.

Remember that the cluster array can only be located and moved on data point locations that are represented by a zero on the boundary or classification tape. Thus, classified data points on the classification map will also act as boundaries to the cluster array, and a smaller-sized array can be used on the second clustering pass, because there is less chance of mixing data from two spectrally distinct features in the same cluster. Figure 16 shows the output of the second pass cluster tape and Table 6 lists the original cluster mean vectors, population, and class designation. Since there are already 7 classes, the cluster numbering starts with cluster 8. Figures 17, 18, and 19 are the scatter diagrams for the mean vector components for the clusters labeled with the corresponding class number. Figures 20 and 21 show enlarged portions of the second pass cluster and classification map, respectively, which correspond to the aerial photograph in Figure 13, and Figure 22 shows the entire classification map. Table 7 lists the single character computer symbols used to represent cluster and class number and Table 8 lists the class mean vector components. Table 9 lists the area percentages for each category in the classification map.

Figure 15. Enlarged portion of first pass classification map.

Interpretation of Results

The objectives were to determine how well the computer classification would lend itself to the land use scheme presented in Circular 671, and then to produce a land use map of at least Level I categories. Thus, the first step consisted of examining the available aircraft imagery in conjunction with the cluster and classification maps, and the scatter diagrams of the cluster and class mean vector components. Based upon geographic location, a limited knowledge of the local area, and the color of the ground scene depicted in color infrared aircraft imagery, attempts were made to group the classes into very loosely defined categories of urban, water, cropland, pasture, forests, and swamp areas. Figures 23, 24, and 25 show the result of this grouping in terms of the scatter diagram of class mean vector components. The symbols on the scatter diagram, U, W, C, P, F, and S represent the components of the class mean vectors belonging to urban, water, cropland, pasture, forest, and swamp, respectively. Table 10 lists the class numbers and the tentative categories to which they were assigned. From the 26 classes that were obtained, 2 classes were assigned to cropland, 6 were assigned to forest, 6 were assigned to pasture, 10 were assigned to urban, 1 was assigned to swamp, and 1 was assigned to water. A more specific definition of what the computer classes represent is attempted in the next section where the classification maps are discussed with some of the classes being represented by the same computer symbol and different computer symbols are used to provide black and white contrast.

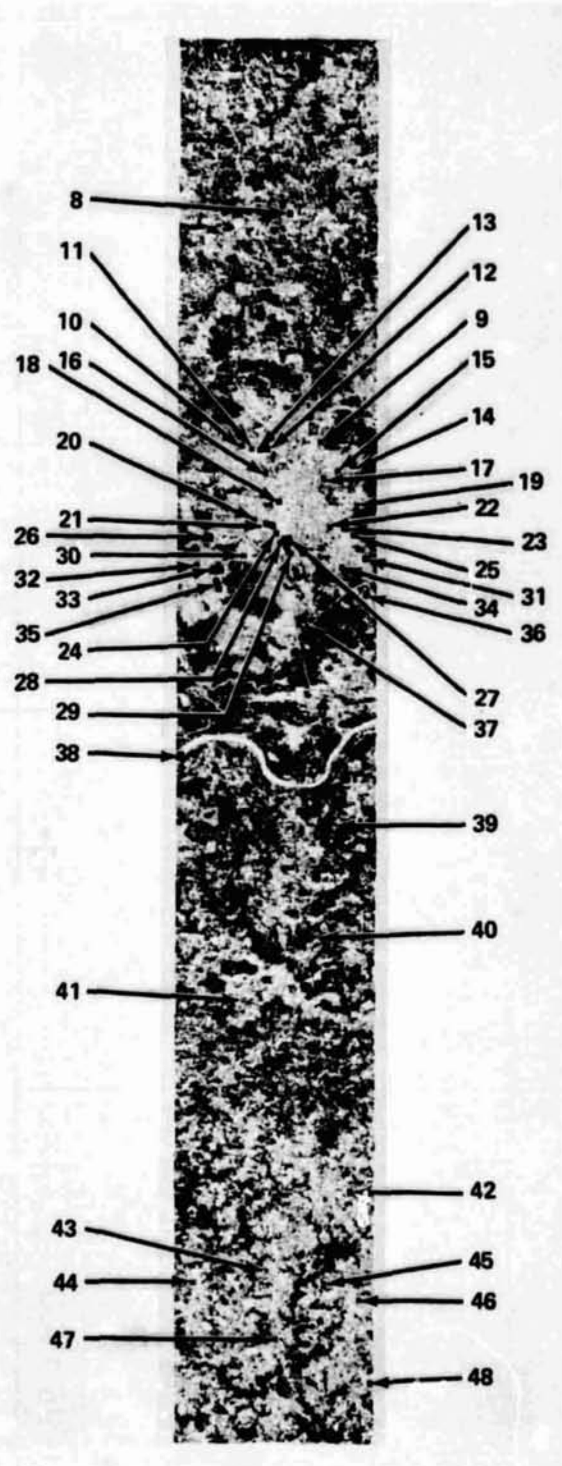


Figure 16. Second pass cluster map using 5 by 5 cluster array.

TABLE 6. MEAN VECTOR COMPONENTS AND POPULATION FOR SECOND PASS CLUSTERS USING A 5 by 5 ARRAY

Cluster	Class	Channel 1	Channel 2	Channel 3	Channel 4	Population
8	8	23.0	14.732	44.39	26.585	41
9	9	24.68	19.12	26.36	14.12	25
10	10	27.36	22.76	32.24	16.92	25
11	11	28.12	23.72	33.8	18.16	25
12	10	27.971	23.771	32.114	16.657	35
13	12	26.52	22.28	30.28	15.84	25
14	12	26.075	20.75	31.6	16.975	40
15	9	25.267	18.667	26.267	13.967	30
16	12	25.0	20.04	29.8	16.44	25
17	13	26.333	21.2	27.0	13.967	30
18	12	25.7	20.733	29.667	15.967	30
19	14	25.36	21.0	28.16	14.68	25
20	12	26.733	21.567	30.033	15.667	30
21	12	26.141	20.962	28.833	15.167	78
22	12	26.8	22.28	30.88	16.16	25
23	15	25.457	19.971	27.457	14.914	35
24	12	27.16	22.08	30.52	15.92	25
25	12	26.457	21.543	30.343	16.229	35
26	12	26.338	21.703	30.959	16.703	74
27	12	26.418	21.525	30.09	15.975	122
28	10	27.174	22.391	31.304	16.478	25
29	12	26.083	21.333	30.292	16.25	25
30	16	26.767	22.933	34.533	18.8	30
31	10	27.429	22.971	32.629	17.029	35
32	17	24.229	16.657	43.314	25.914	35
33	17	23.723	15.773	43.378	25.924	119
34	18	25.04	21.44	32.88	18.56	25
35	17	24.119	16.149	43.634	26.168	101
36	19	26.5	21.467	31.867	17.667	30
37	20	18.64	12.6	12.92	5.4	25
38	21	20.346	12.346	6.096	0.904	52
39	22	19.0	17.72	28.32	16.4	25
40	22	19.4	17.433	28.3	17.767	30
41	23	22.233	16.8	32.667	19.6	30
42	23	23.533	18.867	30.567	16.967	30
43	24	23.32	20.84	28.16	15.48	25
44	23	22.4	18.7	30.925	17.9	40
45	23	22.729	18.729	30.854	17.625	48
46	25	21.76	13.96	43.36	27.12	25
47	23	22.48	18.04	31.24	18.2	25
48	26	22.8	17.1	36.2	21.667	30

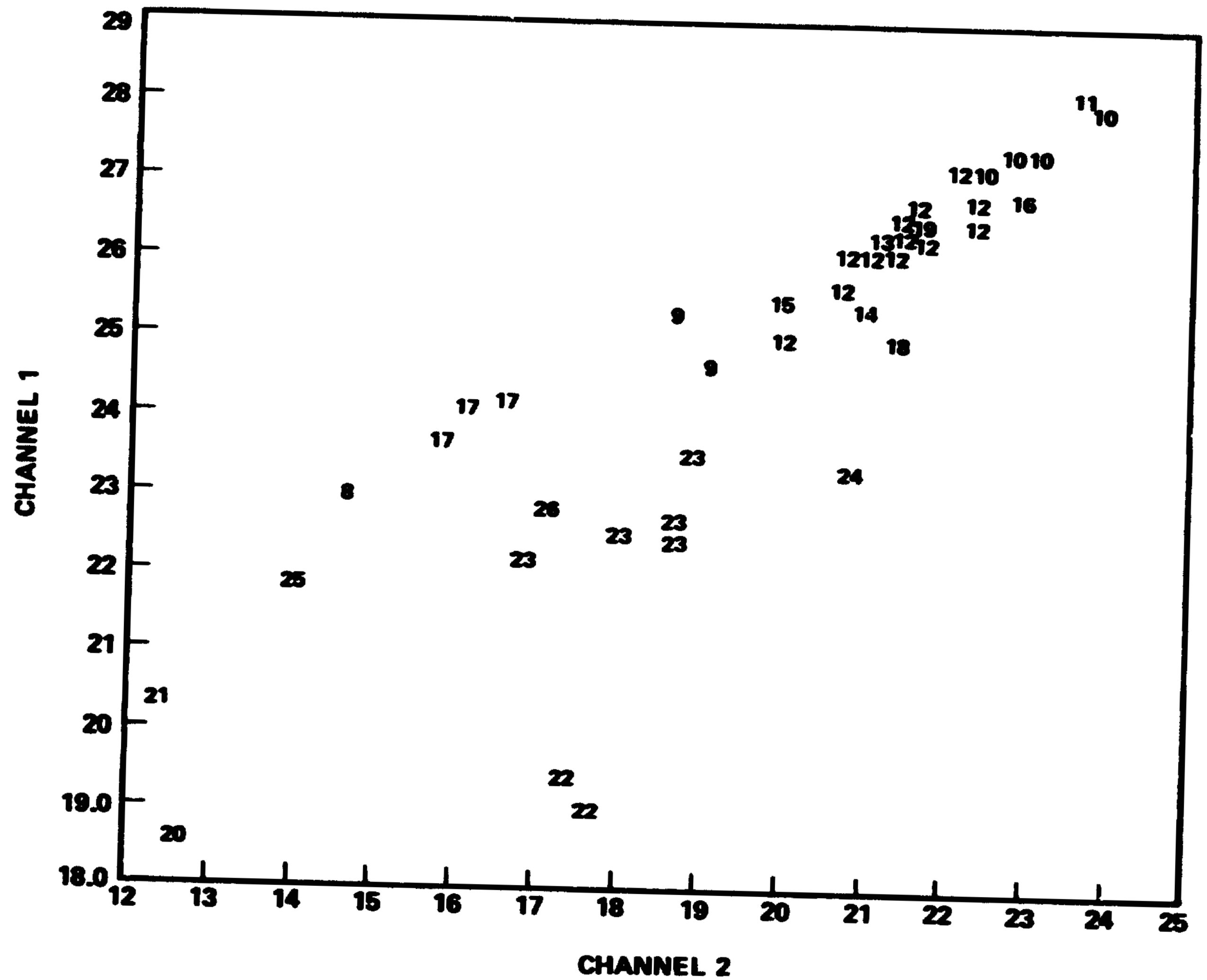


Figure 17. Channel 1 and 2 5 by 5 cluster mean vector components.

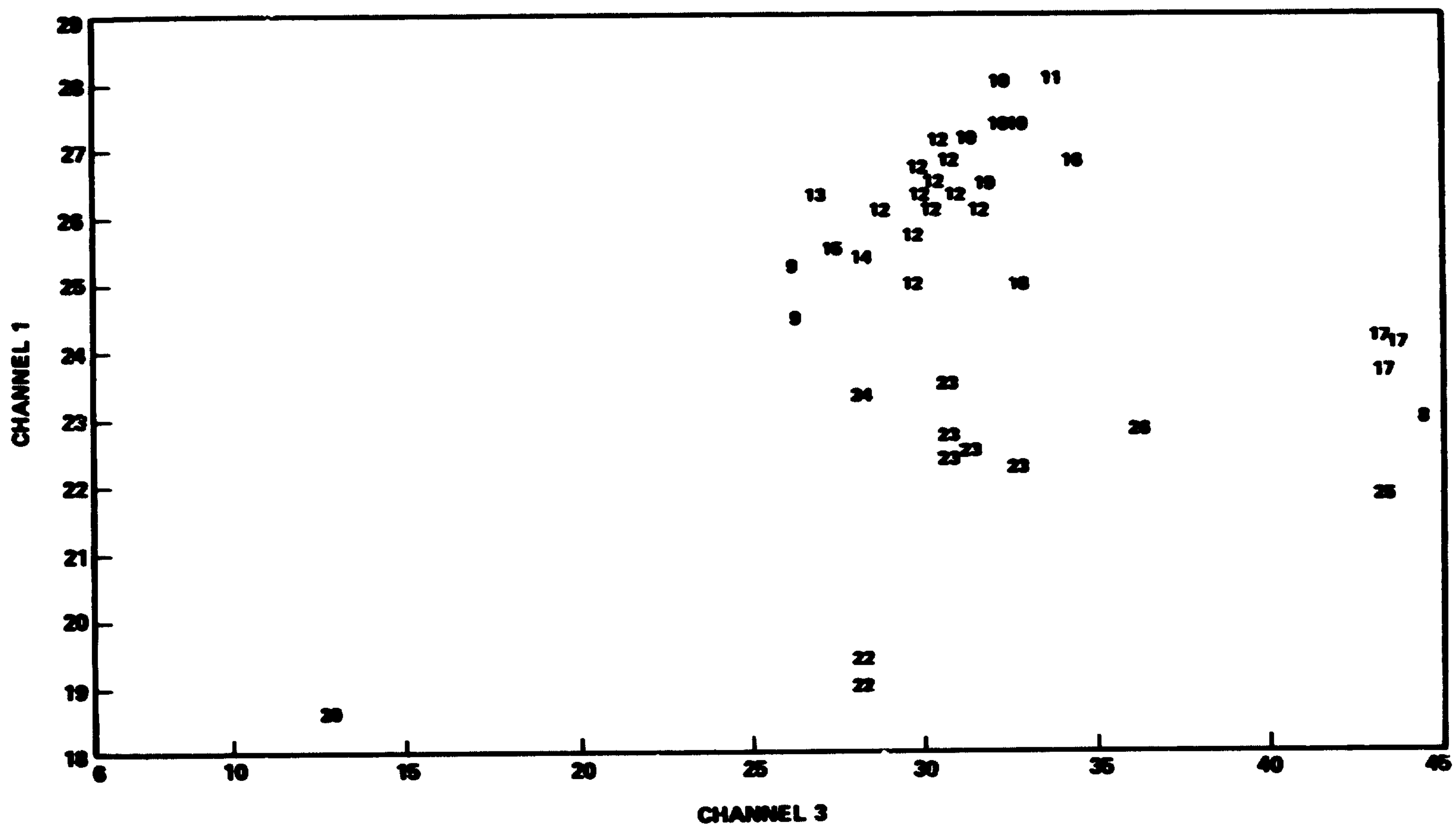


Figure 18. Channel 1 and 3 5 by 5 cluster mean vector components.

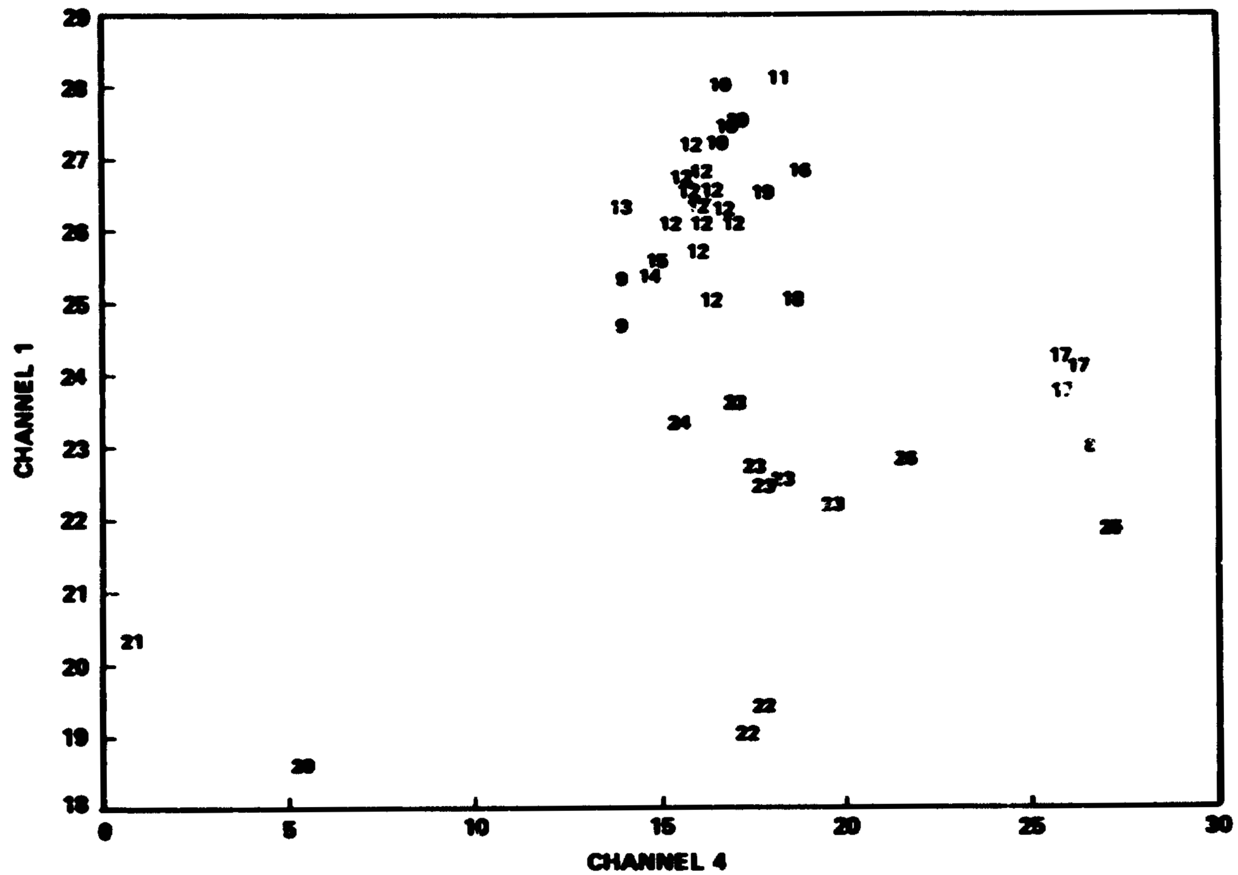


Figure 19. Channel 1 and 4 5 by 5 cluster mean vector components.

Figure 20. Enlarged portion of second pass cluster map using 5 by 5 array.

Figure 21. Enlarged portion of second pass classification map.

Figure 22. Second pass classification map of tape 3, strip 2.

A study of the color infrared aircraft imagery presented several observations pertinent to the land use categories. Apparently, the month of November is not a good month for obtaining different types of crop classification, since most of the known crop areas appeared green or blue green in color. This indicates a lack of chlorophyll, which in turn indicates that the crops had probably been harvested or at least had reached the end of their growing cycle. This would also account for the fact that there were only two classes associated with the locations of the crop areas, and these classes were observed along the entire length of the classification map. These crop classes also tended to show up in backyards and other urban areas. The areas which appeared to have healthy growing vegetation, indicated as various shades of pink or red in color imagery, correlated very highly with known pasture or cattle grazing areas. These areas also appeared in backyards, where winter grass was apparently sown, or on well kept golf courses. Some known pasture areas are covered with trees and these areas would be classified as forest rather than pasture. It was hoped that in the forest categories, it might be possible to differentiate between softwood and hardwood trees. However, the classes obtained for trees appear to be more related to the density of the tree growth. It might be possible to distinguish hardwood and softwood and easier if a different season of data were available and the training areas were manually selected.

The classes for urban indicated that it might be possible, at least in the city of Huntsville, to distinguish in a broad sense residential from other types of

TABLE 7. COMPUTER CHARACTER REPRESENTATION OF CLUSTER AND CHARACTER NUMBER

Cluster or Class Number	Computer Character	Cluster or Class Number	Computer Character
1	1	24	N
2	2	25	O
3	3	26	P
4	4	27	Q
5	5	28	R
6	6	29	S
7	7	30	T
8	8	31	U
9	9	32	V
10	0, Zero	33	W
11	A	34	X
12	B	35	Y
13	C	36	Z
14	D	37	=
15	E	38	$
16	F	39	,
17	G	40	'
18	H	41	(
19	I	42	*
20	J	43	/
21	K	44	+
22	L	45	)
23	M	46	1

TABLE 8. SECOND PASS CLASS MEAN VECTORS

Class	Channel 1	Channel 2	Channel 3	Channel 4
8	23.0	14.732	44.39	26.585
9	25.0	18.873	26.309	14.036
10	27.525	23.051	32.136	16.788
11	28.12	23.72	33.8	18.16
12	26.296	21.386	30.141	16.066
13	26.333	21.2	27.0	13.967
14	25.26	21.0	28.16	14.68
15	25.457	19.971	27.457	14.914
16	26.767	22.933	34.533	18.8
17	23.949	16.043	43.471	26.02
18	25.04	21.44	32.88	18.56
19	26.5	21.467	31.867	17.667
20	18.64	12.6	12.92	5.4
21	20.346	12.346	6.096	0.904
22	19.218	17.564	28.309	17.6
23	22.671	18.312	31.191	18.0
24	23.32	20.84	28.16	15.48
25	21.76	12.96	43.36	27.12
26	22.8	17.1	36.2	21.667

TABLE 9. SECOND PASS CLASS POPULATIONS AND AREA PERCENTAGES

Category	Population	Percentages
Unclassified	15 733	6.12
Class 8	138	0.05
Class 9	3 063	1.19
Class 10	1 619	0.63
Class 11	176	0.07
Class 12	2 798	1.09
Class 13	835	0.32
Class 14	2 466	0.96
Class 15	386	0.15
Class 16	1 449	0.56
Class 17	715	0.28
Class 18	384	0.15
Class 19	565	0.22
Class 20	175	0.07
Class 21	772	0.3
Class 22	2 342	0.91
Class 23	15 552	6.04
Class 24	9 132	3.55
Class 25	480	0.19
Class 26	4 918	1.91

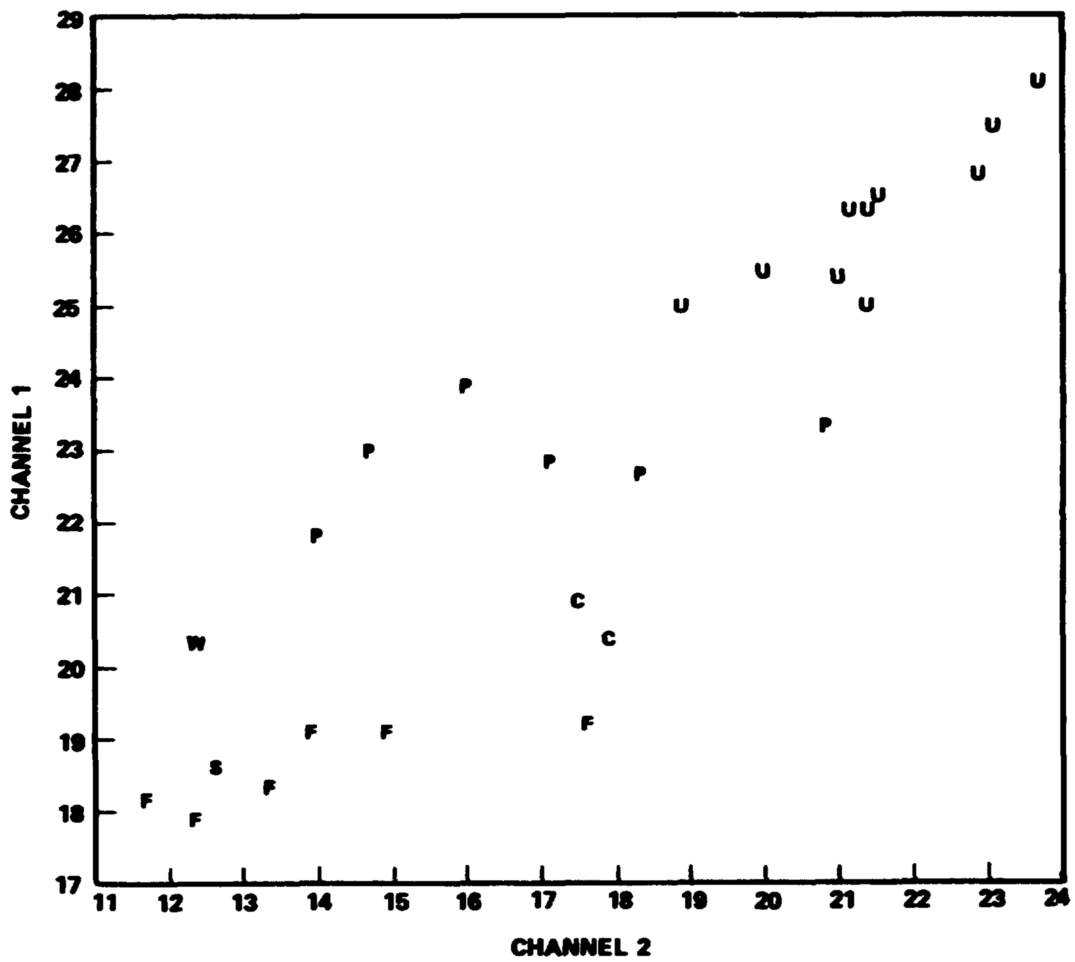


Figure 23. Channel 1 and 2 class mean vector components.

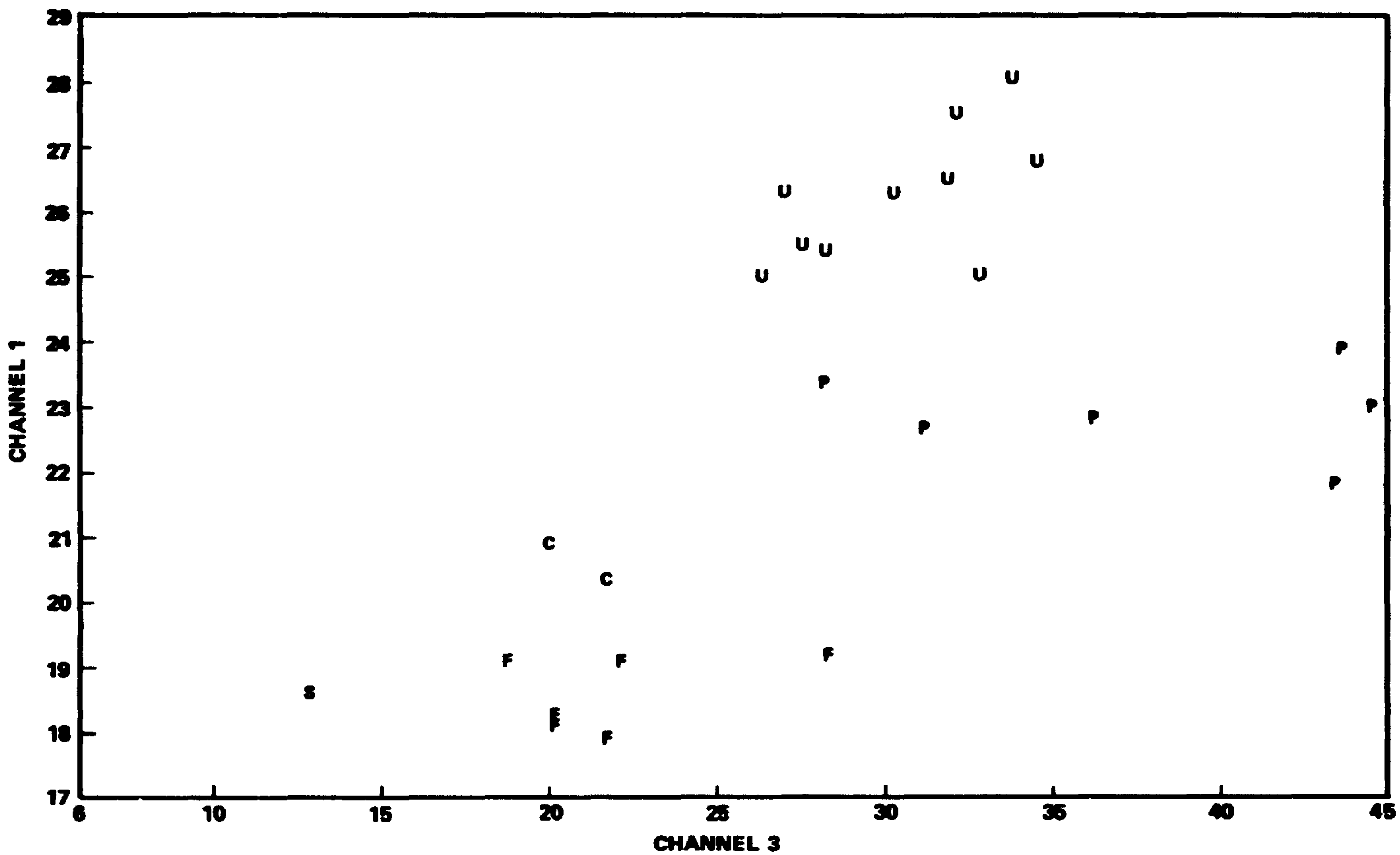


Figure 24. Channel 1 and 3 class mean vector components.

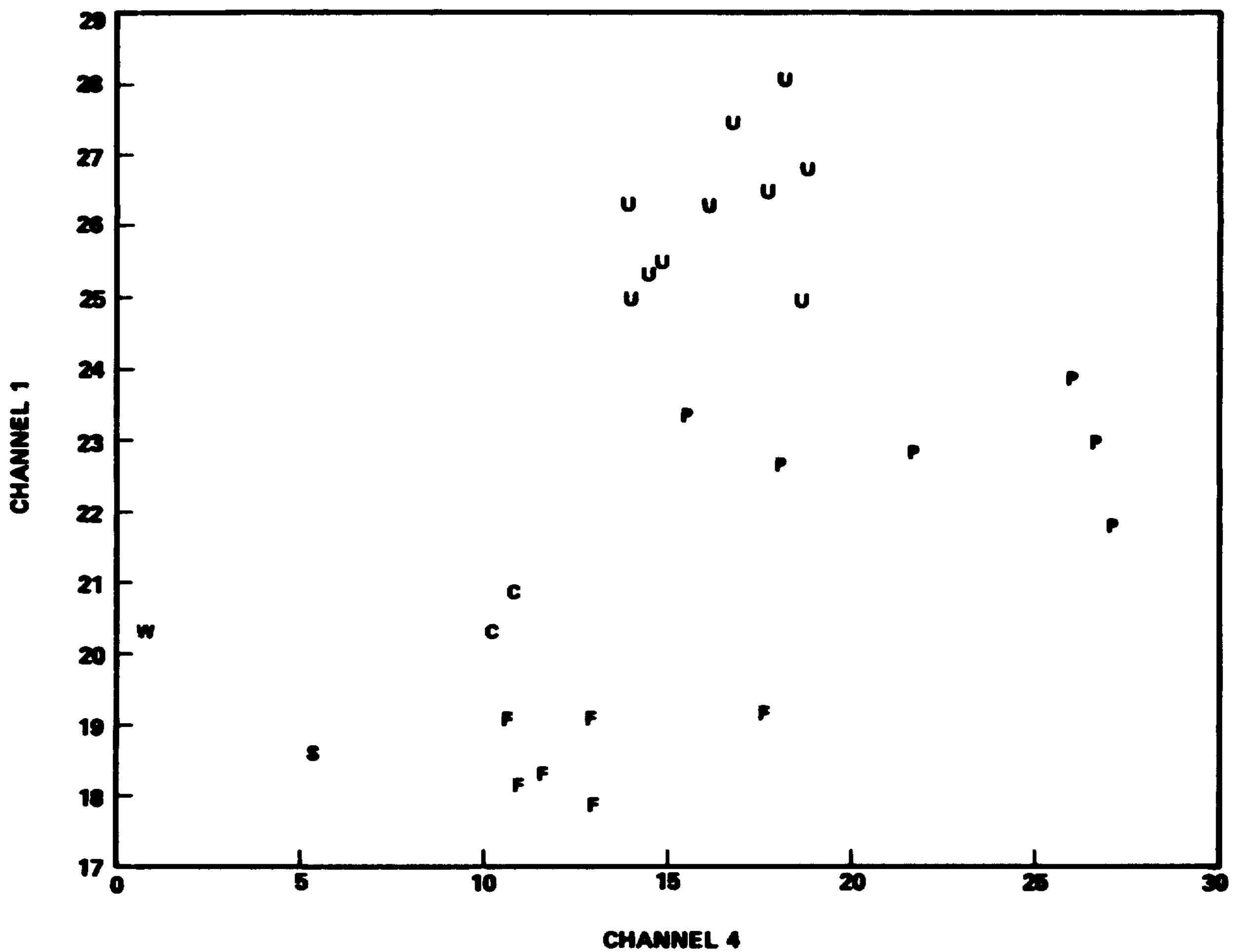


Figure 25. Channel 1 and 4 class mean vector components.

TABLE 10. CLASSIFICATION CATEGORIES

Class	Category	Class	Category
1	cropland	14	urban
2	forest	15	urban
3	cropland	16	urban
4	forest	17	pasture
5	forest	18	urban
6	forest	19	urban
7	forest	20	swamp
8	pasture	21	water
9	urban	22	forest
10	urban	23	pasture
11	urban	24	pasture
12	urban	25	pasture
13	urban	26	pasture

urban area, if the training areas were manually selected. The residential areas tended to have more trees and vegetated lawns, which decreased the brightness on the color aircraft imagery.

The class for water was obtained from a deep portion of the Tennessee River and was quite different in appearance from water occuring in shallow areas. Thus, it was not possible to classify water appearing in small lakes or ponds (areas smaller than a 5 by 5 cluster size) or in small narrow tributaries and rivers branching off from the Tennessee River. The class for swamp was an area that contained trees which were standing in water.

CLASSIFICATION, USING STAND ALONE PROGRAM

Rather than compiling the large composite program for classifying each strip, the classification program was copied and written so that it could be run independently of the composite program. The stand along classification program uses the raw data, statistics, and boundary tapes as inputs, but has the additional option of including or deleting boundary points in the classification analysis. The boundary points were included

in the analysis to see how the area class percentages would change and to get an idea of how much error was involved in classifying boundary points. Table 11 shows the comparison in terms of class area percentages when the boundaries are and are not included in the classification analysis, and Table 12 shows the increase in area percentage for the six land use categories.

TABLE 11. CHANGE IN CLASS PERCENTAGES WHEN BOUNDARY POINTS ARE CLASSIFIED

Category or Class	Boundaries Not Classified		Boundaries Classified		Percentage Change
	Population	Percentage	Population	Percentage	
Unclassified	15 733	6.12	25 497	9.9	3.78
Boundaries	88 957	34.6	0	0	-34.6
1	15 652	6.09	22 045	8.56	2.47
2	8 837	3.44	9 362	3.64	0.2
3	5 243	2.04	6 306	2.45	0.41
4	33 118	12.88	45 039	17.49	4.61
5	4 790	1.86	5 923	2.3	0.44
6	4 618	1.8	5 444	2.11	0.31
7	32 207	12.53	41 660	16.18	3.65
8	138	0.05	237	0.09	0.04
9	3 063	1.19	5 971	2.32	1.13
10	1 619	0.63	2 728	1.06	0.43
11	176	0.07	238	0.09	0.02
12	2 798	1.09	3 933	1.53	0.44
13	835	0.32	1 655	0.64	0.032
14	2 466	0.96	4 186	1.63	0.67
15	386	0.15	472	0.18	0.03
16	1 449	0.56	3 078	1.2	0.64
17	715	0.28	1 297	0.5	0.22
18	384	0.15	333	0.13	-0.02
19	565	0.22	512	0.2	-0.02
20	175	0.07	432	0.17	0.1
21	772	0.3	918	0.36	0.06
22	2 342	0.91	4 001	1.55	0.64
23	15 522	6.04	37 191	14.44	8.4
24	9 132	3.55	17 810	6.92	3.37
25	480	0.19	1 139	0.44	0.25
26	4 918	1.91	10 133	3.93	2.02

TABLE 12. AREA PERCENTAGE INCREASE OF LAND USE CATEGORIES WHEN BOUNDARIES ARE CLASSIFIED

Land Use Category	Area Percentage Increase
cropland	2.88
forest	9.85
pasture	14.3
urban	3.64
water	0.06
swamp	0.1
Total	30.83

Examination of Table 11 indicates that all classes had an increase in population except for two urban classes. This is probably due to the spatial priority assignment used in the classification program which produces an effect that is particularly noticeable when two classes are competing for the same area that should possibly have been merged. The logic used in the classification procedure starts on the left side of the map and moves to the right side. After a scan has been completed, the classification starts again on the left side of the map on the next scan. With two classes that are close together spectrally, the logic produces a map that has a somewhat streaked appearance in the northwest, southeast direction. This effect generally does not hurt the accuracy as long as a category or definition is used which includes the two classes, since the two classes can be written on the map with the same computer symbol.

While obtaining the classification results, the original raw data tape 1 went bad, and therefore it is not possible to show classification results for the entire test area. The problem of tapes going bad was anticipated, but the preventative action taken was not sufficient. Initially, a reformatted tape and a copy were made from the raw data tape originally obtained from Goddard Space Flight Center. On occasion, however, the reformatted tape and its copy would be bad at the same time, and it was necessary to go back to the original raw data tape once too often. Therefore, it is highly recommended that a copy or two be made from the original tape on initial receipt of the data.

Figure 26 shows the classification map for the eastern two thirds of the test area using 26 classes. The class number, computer symbol and category are listed in Table 13. Although it is not possible to read the symbols on the map, it is possible to distinguish shades of grey. The darker areas on the map represent a combination of urban, pasture, and cropland, except along the Tennessee River where the dark area represents water. The lighter shades of grey represent forest Examination of the map reveals that classes

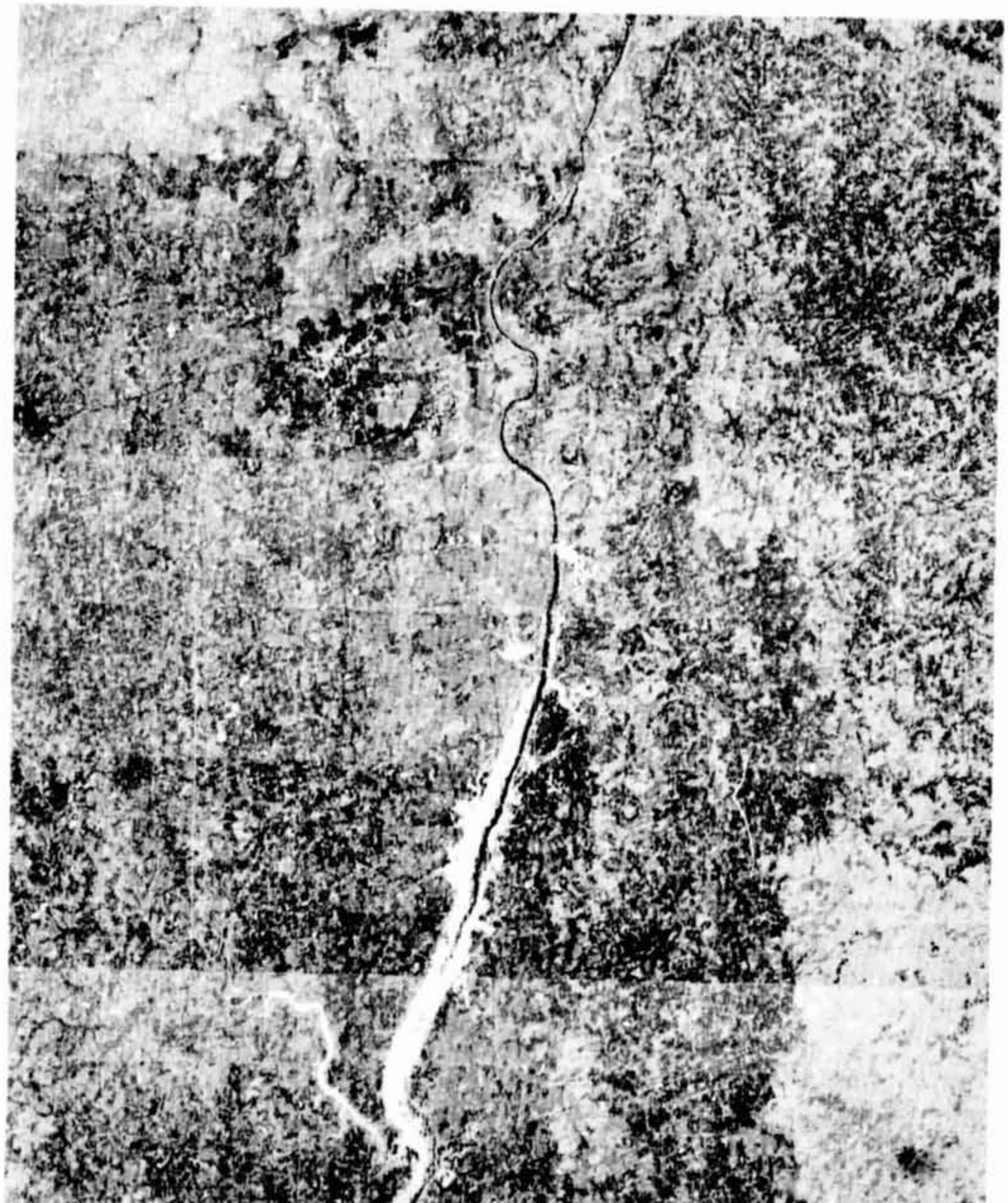


Figure 26. Classification map for tapes 2 and 3.

TABLE 13. 26 CLASS MAP COMPUTER SYMBOLS AND CATEGORIES

Class Number	Computer Symbol	Category	Class Number	Computer Symbol	Category
0	blank	unclassified	14	u	urban
1	+	cropland	15	u	urban
2	/	forest	16	u	urban
3	+	cropland	17	x	pasture
4	/	forest	18	u	urban
5	.	forest	19	u	urban
6	/	forest	20	*	swamp
7	.	forest	21	w	water
8	x	pasture	22	–	forest
9	u	urban	23	x	pasture
10	u	urban	24	x	pasture
11	u	urban	25	x	pasture
12	u	urban	26	x	pasture
13	u	urban			

representing different types of water are missing, since the shallower parts of the Tennessee River and tributaries are unclassified. Thus, it will be necessary to do more clustering and to combine some of the class symbols to produce a classification map with more contrast. Compare Figure 26 with Figures 2, 3, and 7.

The definitions of the class categories are re-examined in terms of the map in Figure 26 in an attempt to be more specific. The definition of cropland in terms of classes 1 and 3 appears to be non-forested but vegetated areas, and the vegetation appears to have completed its growing cycle. In order for classes 1 and 3 to represent cropland only, it would probably be necessary to obtain seasonal ERTS data, where a plowing and growing cycle could be observed. Certainly, classes 1 and 3 represent areas that can be easily used as cropland.

The category pasture, represented by classes 8, 17, 23, 24, 25, and 26, appears to be non-forested but vegetated areas, and the vegetation is still in the growing cycle. It is possible that some confusion may exist on the map between cropland and pasture, but the confusion is somewhat lessened by the high degree of correlation between known pasture areas shown on the map and the probability that the growing season for most crops has been completed. Again, seasonal data is needed to reduce the uncertainty, but no amount of data would help in picking out pasture areas covered with trees. Both of the categories, cropland and pasture, do represent areas that could easily be used for agricultural purposes.

The classes representing forest (2, 4, 5, 6, 7, and 22) as a whole appear to be very acceptable. As subcategories of forest, the classes do appear to correlate highly with tree density, but the accuracy of some of the classes need to be improved as indicated by the streaked forested areas on Figure 26.

The urban classes (9, 10, 11, 12, 13, 14, 15, 16, 18, and 19) appear to represent various types of residential areas depending on yard space, number of trees, and density of houses. The unclassified part of the City of Huntsville correlates very highly with the business district and large shopping centers along the major throughfares. The business structures at NASA on Redstone Arsenal and the Huntsville-Decatur Jetport are also unclassified urban areas.

The swamp area (class 20) is forested wetland, and water (class 21) appears to represent water contained in the deep channel of the Tennessee River, which has a different turbidity from the rest of the water in the river. The categories of cropland, pasture, forest, urban, swamp, and water will continue to be used, but with the above mentioned qualifications. Misclassification occurring in some of the boundary areas is apparent, but it does not seem to present a serious problem.

Tables 14 and 15 list the population and percentages for each class contained on the two data tapes that were divided into four strips each, while Table 16 lists the population and percentages for each land use category as a function of tape and strip. Table 17 lists the land use category population and area percentages for all of Figure 26.

In order to obtain additional classes for water, tape 2 strip 4 was input to the clustering program and the location of the newly acquired clusters is shown in Figure 27. Table 18 lists the mean vectors for the new clusters, assigned class number and the population for ach cluster, while Table 19 lists the mean vectors for the new classes and land use categories.

FINAL RESULTS

There are four basic types of output that can be used for examining the classification maps and these are computer printout, Xerox microfilm copy, the microfilm negative itself, and photographs made from the microfilm negatives. Thus, the maps can be examined at a wide variety of scales. However, no attempt has been made to produce an output that is geographically correct. The main reason for not attempting to scale the data for geographic accuracy is that the scale would probably have to be changed, in two directions, every time data from a different set of scanner data is used. In one direction the scale would depend on the data sampling rate (samples/scan/channel), and in a direction perpendicular to that, the scale would depend upon the scanning rate. The second reason is that the computer characters used on the map are generally longer than they are wide and there is no readily available way to easily ary their dimensions. The data associated with one ERTS image contains 3,240 samples/scan and 2,340 scans, so that

TABLE 14. CLASS POPULATION AND AREA PERCENTAGES FOR TAPE 2

Class	Tape 2							
	Strip 1		Strip 2		Strip 3		Strip 4	
	Population	Percent	Population	Percent	Population	Percent	Population	Percent
0	32 884	12.77	30 620	11.89	3[illegible]	12.82	32 674	12.56
1	11 799	4.58	11 835	4.6	15 498	6.02	20 671	7.95
2	8 872	3.44	5 127	1.99	5 239	2.03	4 854	1.87
3	7 628	2.96	6 732	2.61	7 137	2.77	14 671	5.64
4	54 756	21.26	54 120	21.01	44 544	17.3	42 532	16.35
5	3 718	1.44	3 499	1.36	4 771	1.85	4 583	1.76
6	6 303	2.45	6 450	2.5	5 387	2.09	4 940	1.9
7	48 474	18.82	51 798	20.11	43 145	16.75	32 459	12.48
8	161	0.06	153	0.06	175	0.07	295	0.11
9	6 408	2.49	6 516	2.53	7 613	2.96	7 928	3.05
10	248	0.1	217	0.08	850	0.33	810	0.31
11	15	0.01	18	0.01	94	0.04	72	0.03
12	823	0.32	874	0.34	1 999	0.78	2 141	0.82
13	717	0.28	606	0.24	1 292	0.5	1 665	0.64
14	3 022	1.17	3 258	1.26	4 283	1.66	4 505	1.73
15	442	0.17	455	0.17	646	0.25	653	0.25
16	1 207	0.47	1 156	0.45	1 989	0.77	2 107	0.81
17	919	0.36	945	0.37	1 393	0.54	1 726	0.66
18	489	0.19	389	0.15	440	0.17	442	0.17
19	313	0.12	277	0.11	437	0.17	448	0.19
20	178	0.07	319	0.12	156	0.06	284	0.11
21	1 656	0.64	334	0.13	1 513	0.59	1 204	0.46
22	3 511	1.36	3 220	1.25	1 970	0.76	1 442	0.55
23	34 019	13.21	38 708	15.03	40 936	15.89	40 616	15.62
24	19 882	7.72	19 865	7.71	19 773	7.68	21 614	8.31
25	642	0.25	816	0.32	1 143	0.44	1 380	0.53
26	8 464	3.29	9 253	3.59	12 116	4.7	13 354	5.13

TABLE 15. CLASS POPULATION AND AREA PERCENTAGES FOR TAPE 3

Class	Tape 3							
	Strip 1		Strip 2		Strip 3		Strip 4	
	Population	Percent	Population	Percent	Population	Percent	Population	Percent
0	23 487	9.12	25 507	9.9	23 059	8.95	32 247	12.01
1	47 420	10.65	22 045	8.56	18 674	7.25	10 863	4.18
2	5 662	2.2	9 362	3.64	18 618	7.23	23 410	9.00
3	10 023	3.89	6 306	2.45	5 826	2.26	4 078	1.57
4	45 020	17.48	45 039	17.49	48 054	18.66	49 825	18.16
5	5 015	1.95	5 923	2.3	4 129	1.6	5 146	1.98
6	3 803	1.48	5 444	2.11	4 887	1.9	6 780	2.61
7	41 880	16.26	41 660	16.18	45 438	17.64	58 114	22.34
8	178	0.07	237	0.04	344	0.13	211	0.08
9	5 164	2.01	5 971	2.32	3 890	1.51	3 204	1.23
10	572	0.22	2 728	1.06	905	0.35	269	0.1
11	39	0.02	238	0.09	61	0.02	17	0.01
12	1 226	0.48	3 933	1.53	1 043	0.4	586	0.23
13	1 062	0.41	1 655	0.64	697	0.27	776	0.3
14	3 591	1.39	4 186	1.63	2 601	1.01	2 364	0.91
15	349	0.14	472	0.18	248	0.10	174	0.07
16	1 986	0.77	3 078	1.2	2 076	0.81	760	0.29
17	1 052	0.41	1 297	0.5	1 625	0.63	867	0.33
18	353	0.14	333	0.13	306	0.12	149	0.06
19	300	0.12	512	0.2	225	0.09	118	0.05
20	530	0.21	432	0.17	166	0.06	165	0.06
21	1 129	0.44	918	0.36	777	0.3	884	0.34
22	3 205	1.24	4 001	1.55	5 187	2.01	7 968	3.06
23	40 755	15.82	37 191	14.44	37 593	14.6	28 845	11.09
24	21 539	8.36	16 810	6.92	16 379	6.36	13 053	5.02
25	923	0.36	1 139	0.44	2 053	0.8	2 225	0.86
26	11 287	4.38	10 133	3.93	12 689	4.93	7 997	3.07

TABLE 16. LAND USE CATEGORY POPULATION AND AREA PERCENTAGES FOR TAPES 2 AND 3

	Tape 2							
	Strip 1		Strip 2		Strip 3		Strip 4	
Category	Population	Percent	Population	Percent	Population	Percent	Population	Percent
unclassified	32 884	12.77	30 620	11.89	33 012	12.82	32 674	12.56
cropland	19 427	7.54	18 567	7.21	22 635	8.79	35 342	13.59
forest	125 634	48.77	124 214	48.22	105 056	40.78	90 810	34.91
pasture	64 087	24.89	69 740	27.08	75 536	29.32	78 985	30.36
urban	13 684	5.32	13 756	5.34	19 642	8.63	20 811	9.0
swamp	178	0.07	319	0.12	156	0.06	274	0.11
water	1 656	0.64	334	0.13	1 513	0.59	1 204	0.46
	Tape 3							
unclassified	23 487	9.12	25 507	9.9	23 059	8.95	31 247	12.01
cropland	37 443	14.54	28 351	11.01	24 500	[illegible]	14 491	5.75
forest	103 865	40.61	111 429	43.27	126 313	49.04	151 243	58.15
pasture	75 734	29.4	67 807	26.32	70 683	27.45	53 198	20.45
urban	14 642	5.7	23 106	8.98	12 052	5.68	8 422	3.25
swamp	530	0.21	432	0.17	166	0.06	165	0.06
water	1 129	0.44	918	0.36	777	0.3	884	0.34

TABLE 17. TOTAL POPULATION AND AREA PERCENTAGES FOR LAND USE CATEGORIES ON TAPES 2 AND 3

Category	Population	Percentage
unclassified	232 490	11.26
cropland	200 756	9.74
forest	938 564	45.44
pasture	555 770	26.94
urban	126 115	6.11
swamp	2 220	0.11
water	9 415	0.41

the data set is approximately 1.38 times wider than it is long, even though the sides of the image are of equal length. The computer characters tend to compensate for this effect, since they are longer than they are wide, and a map results that is not too badly distorted for ERTS data.

In order to get an idea of the scales involved, the different types of computer output were compared with the 1:24,000 scale TVA maps. The east-west scale of the computer printout is 0.84 times that of the TVA maps, while the north-south scale of the printout is 1.56 times that of the TVA maps. Thus, the classification map on the computer printout will be 1.86 times longer than it should be. The Xerox copy is 0.5 times as wide and 0.61 times as long as the TVA maps, or 1.22 times wider than it should be. The microfilm is approximately 0.055 times as long and 0.044 times as wide as the TVA maps, while the photography obtained from the microfilm negatives can

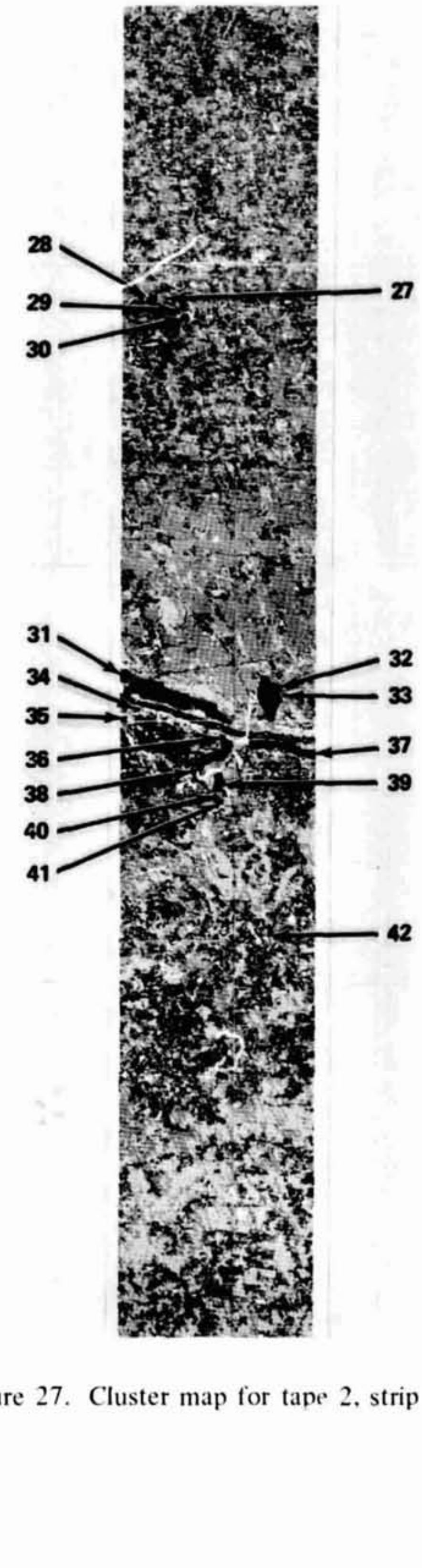


Figure 27. Cluster map for tape 2, strip 4.

TABLE 18. CLUSTER STATISTICS FOR TAPE 2, STRIP 4

Cluster	Class	Channel 1	Channel 2	Channel 3	Channel 4	Population
27	27	27.92	26.12	27.28	13.0	25
28	27	27.848	26.758	27.071	12.636	99
29	28	28.771	28.886	31.2	15.457	35
30	29	26.638	21.468	41.362	23.255	47
31	30	25.488	18.555	9.813	1.862	1756
32	31	25.229	22.052	12.959	2.467	734
33	32	25.52	23.84	15.96	3.8	25
34	33	32.067	28.7	29.533	13.333	30
35	34	28.2	24.657	23.086	9.829	35
36	35	25.54	19.81	12.121	2.534	494
37	36	27.776	24.605	18.273	4.782	509
38	37	25.375	20.875	13.958	4.0	25
39	32	25.983	23.657	17.023	4.451	175
40	32	26.057	24.314	17.371	4.4	35
41	32	25.39	23.39	17.927	5.0	41
42	38	31.36	28.48	27.16	11.52	25

TABLE 19. CLASS STATISTICS FOR TAPE 2, STRIP 4

Class	Category	Channel 1	Channel 2	Channel 3	Channel 4
27	urban	27.873	26.629	27.113	12.71
28	urban	28.771	28.886	31.2	15.457
29	pasture	26.638	21.468	41.362	23.255
30	water	25.488	18.555	9.813	1.862
31	water	25.229	22.052	12.959	2.467
32	water	25.862	23.717	17.105	4.467
33	urban	32.067	28.7	29.533	13.333
34	urban	28.2	24.657	23.086	9.829
35	water	25.54	19.81	12.121	2.534
36	water	27.776	24.605	18.273	4.782
37	water	25.375	20.875	13.958	4.0
38	urban	31.36	28.48	27.16	11.52

be made to vary in scale. Table 20 gives the approximate scales for ERTS data and the standard map outputs. The Xerox map for the area analyzed on the computer is approximately 7 feet (2.1 meters) by 8 feet (2.5 meters), while the printout map is approximately 18 feet (5.5 meters) by 13.3 feet (4.1 meters). In area size, the computer test area was approximately 60 miles (86 kilometers) by 66.5 miles (106.4 kilometers), or 3,990 square miles (10,214 square kilometers).

TABLE 20. APPROXIMATE SCALES FOR CLASSIFICATION MAPS

Output	Approximate Scale	
	North-South Direction	East-West Direction
Printout	1:15,385	1:28,571
Xerox Copy	1:39,344	1:48,000
Microfilm	1:435,538	1:536,360

Figure 28 is a four category map, with water and swamp represented by the symbol 0, cropland and pasture represented by X, urban by ., forest by/, and blank represents unclassified data. The categories were combined down to four in order to produce some contrast.

In order to see more detail, the next three maps have at most only three categories. Figure 29 shows the categories water, swamp and urban represented by W, ., /, respectively, while Figure 30 shows water (no swamp), pasture, and cropland represented by /, X, and ., respectively. Figure 31 shows water (no swamp) and forest represented by W and /. Table 21 shows the population and area percentages for each land use category for the entire data set. Compare Figures 28 through 31 with Figures 2, 3, 7, and 26.

In order to have a comparison of time estimates in making the land use map, it will again be mentioned that the programs were run on an IBM-7094/44, but that no recommendation is being made for using any particular computer system. The computer time includes compilation and printing time. The boundary program runs approximately 224 samples/second and took 4 hours to produce the map in Figure 6. It would not be generally necessary to get boundary maps for the entire test area, but the maps are presently being examined for other purposes. The composite program, run on tape 3 strip 2 producing Figures 8, 14, 16, and 22, ran for 57 minutes. The length of time that the composite program runs will depend considerably on the number of clusters and classes, which in this case were 48 and 26, respectively.

Figure 28. Land use map showing agriculture, urban, forest and water categories.

Figure 29. Land use map showing water, swamp, and urban categories.

Figure 30. Land use map showing water, pasture, and cropland categories.

Figure 31. Land use map showing water and forest categories.

TABLE 21. LAND USE CATEGORY POPULATION AND AREA PERCENTAGES

Category	Population	Percentage
unclassified	154 140	7.47
cropland	193 832	9.39
forest	938 885	45.51
pasture	551 287	26.72
urban	180 599	8.75
swamp	2 160	0.1
water	42 547	2.06

The map shown in Figure 26 was produced by using the stand alone classification program and took 3 hours 16 minutes and 40 seconds. The running time of this program also depends on the number of classes, but for 26 classes it ran approximately 175 samples/second. The additional clustering performed on tape 2, strip 4 shown in Figure 27 took 34 minutes and 43 seconds. The classification program used to produce the 4 category land use map shown in Figure 28 took 3 hours 49 minutes and 4 seconds. For 38 classes the program runs approximately 150 samples/second. Normally, Figure 28 would be the end product and the analysis would stop there, but, to provide visibility to the accuracy of the results, Figures 29, 30, and 31 were generated. These were generated with a program which does nothing but assigns computer symbols to the classes contained on the classification tape. It took 1 hour 55 minutes and 12 seconds to produce each figure, and the program ran at approximately 448 samples/second. The total amount of computer used to produce the results shown in Figures 6, 8, 14, 16, 22, 26, 27, 28, 29, 30, and 31 came to 19 hours 23 minutes and 3 seconds.

Composite Sequential Clustering Program (CSCP)

BRIEF HISTORY OF THE PROGRAM

The composite sequential clustering algorithm (CSCP) is a combination of two algorithms that have been in use for some time. These are a sequential clustering algorithm and a K-means algorithm. The contribution cited in Reference 4 was the interfacing of the two algorithms in one computer program.

Initially the decision was made to develop a classification program that was entirely sequential, i.e., only one pass through the data was required. Certain drawbacks exist in allowing only one pass, however. In a sequential algorithm classes are initiated, data points are added, and statistics are continuously updated. The net result is that a sample classified into a given class near the beginning of the classification map might not be classified into the same class if it occurred near the end of the classification map. This can cause a considerable reduction in classification accuracy. With classification accuracy as a desired feature, a literature survey was undertaken. The K-means algorithm in its original form used an initial guess of class mean vectors and then iterated to improve classes. The better the initial guesses were, the faster the convergence to final classifications was. The need for initial classes prompted the use of a sequential algorithm to generate initial classes. The CSCP was the result. The sequential program generated these initial classes, and the K-means algorithm iterated to improve classification accuracy.

DESCRIPTION

The CSCP consists of the two main sections, mentioned above, the sequential portion, and the K-means portion. The sequential clustering section begins by establishing an initial class. As written, the program begins by reading and storing in the XDATA array, the first six points in the sample sequence. The mean vector for these six points is calculated and then the parameter ΔX_i^2 is calculated for each sample, where

$$\Delta X_i^2 = \sum_{k=1}^{K} (X_i, k - \overline{X}_1, k)^2 \quad ,$$

i refers to the sample number, 1 to the 1st class, and k to the channel. The maximum value to ΔX_i^2 for the six samples is found, and if

$$\frac{\Delta X^2{}_{max}}{|\overline{X}_1, k|^2} \leqslant \text{THRESH} \quad , \tag{11}$$

then the six samples will be designated as a class. THRESH is an input parameter set to 0.75 for all cases reported in this report. If the test is not met then the first sample in the sequence is discarded. A new sample is read in and the test is performed again with the revised six samples. This process is continued until equation (11) is satisfied, which means that a class is formed. Once the first class is formed, each following sample point is checked using two tests, a Chi-square and normal test, to see if it belongs to the established population. These tests are discussed at length in Reference 4 and will not be

repeated here. If the sample does belong to the established pouplation, the class statistics will be updated. If the sample does not satisfy the two tests it is placed into the XDATA array. If the number of points in the XDATA array is six, these six points will be subjected to the test of equation (11) to see if they constitute a new class. If not, the first sample put in the XDATA is discarded and the process continues. Eventually, a number of classes will be established and each sample will be either used to update the statistics of the class to which it belongs or the sample will be put into the XDATA array, and possibly be used to establish a new class.

If the number of classes exceed the input value of MAXPØP, subroutine REDPØP is called to merge the two most "similar" classes. The (symmetric) distance matrix composed of the Euclidean distances between each of the class means is calculated. The two classes, whose Euclidean distance between centroids is the smallest of all the elements of the distance matrix are the two classes that are merged. The merging procedure is continued as necessary until the end of the raw data tape is encountered. When this occurs the raw data tape is rewound and the class mean vectors are used as inputs to the K-means portion of the program.

The K-means portion of the program takes the cluster centers, either input to the program on computer cards or calculated by the sequential part of the program, and iterates through the data NITER times (NITER was set to 3 for this report) to improve classification. How the program can be used on means as input to the program on cards will be discussed in a later section.

The iteration takes the following form. The Euclidean distance squared from the sample to each of the class means is calculated and the sample is classified into the classes for which the distance squares is the least. Statistics for this class are updated to include the new sample. Once the end of the raw data tape is reached, control is shifted to subroutine CMAP which prints out a classification map and the iteration statistics. If the maximum number of iterations (NITER = 3) has not been exceeded, then the new class means are used to begin the K-means classification again. Note that in beginning the K-means iteration the means from the previous iteration are used to classify, and completely new statistics are being calculated. The means from the previous iteration are not continuously updated, but are completely recalculated. Once the end of the sample sequence is reached and the number of iterations equals NITER, the final classification map and statistics are printed out. One last option was generally utilized in the preparation of this report. If the input parameter NDØUBL is set to 1, a double track boundary map is printed out. This map prints out only the border of areas of homogeneous classification, and leaves the interior of the area blank. In many cases this allows easy location of features that would be hard to find otherwise.

PROGRAM CHANGES

Most of the material in the previous section is contained in Reference 9. Discussion of many of the options available in the program was not mentioned for the simple reason that they were not used for the preparation of this report. Since the publication of Reference 9, a few changes in the program have been made which will now be described. One major hange concerns the Chi-square tables used in the test in the sequential part of the program. The original data used tables for a 99 percent level of confidence. For all data analyzed up to that time, the 99 percent tables had been adequate. When the analysis of ERTS data of the Huntsville area was undertaken, only three or four classes were established, which was highly inadequate. The need for lower confidence limit tables was not anticipated and the 99 percent tables were being input at compile time with a DATA statement. So that the program would not need changing each time new tables were used, the program was revised to read in the tables with a NAMELIST statement. In addition, new Chi-square tables for a level of confidence of 80 percent replaced the old tables. Most statistics books have Chi-square tables for from 1 to 30 degrees of freedom (n) and perhaps for other selected values of n (e.g., n = 50, 100, 00 ...). The program requires values of n from 1 to 201. The fact that the Chi-square distribution approaches the normal distribution for large values of n is well known. Some functions of n and Chi-square approach the normal distribution much faster than Chi-square itself so that approximate values of Chi-square for any value of n can be calculated. One particularly good approximation for Chi-square described in Reference 12 is

$$X^2_{n;\alpha} = n\left[1 - \frac{2}{9n} + Z_\alpha\left(\frac{2}{9n}\right)^{1/2}\right]^{1/3} \tag{12}$$

where Z is the normal deviate for given level of confidence. For example, for the 80 percent level of confidence $X^2_{n;.900}$ and $X^2_{n;.100}$, $Z_{.900}$ is approximately -1.28 and $Z_{.100}$ is +1.28. To generate the 80 percent tables, these values of Z were used in the approximation of equation (12).

ANALYSIS PROCEDURES

The general problem addressed in automated land use classification with unsupervised classification programs is to generate classes that can be easily interpreted. The CSCP can be used in either an unsupervised or in a supervised mode. In the unsupervised mode no human data interpretation is required prior to a run. In the supervised mode, subjective human judgements are required before the data is analyzed. When using the CSCP on satellite data, such as the ERTS data, where lighting conditions are relatively uniform across the entire image, the following procedure is generally

followed. The program is initially clustered on a small area using the unsupervised mode. The clustering consists of establishing classes with the sequential section and then iterating to improve the classes with the K-means algorithm. The second step requires subjective human judgements concerning the interpreting of the classes. The aim in the preparation of this paper was to be able to interpret classes corresponding to Level I categories in the classification scheme outlined in the USGS circular 671. In the data analyzed, the initial step resulted in 15 classes. The next step was to compare the classification map with existing aerial photography, which in this case was the high-altitude RB-57 data used in making the photomosaic. From this analysis, two classes were found to be combinations of two or more useful classes and could not readily be given a Level I name. The decision was made to completely eliminate these two classes from further consideration. Discarding the 2 classes left 13 classes to be used in the next phase of the analysis. With only these mean vectors as input to the CSCP and MAXPØP set to 13, it is now possible to completely bypass the sequential part of the CSCP. To do this, MBYPASS is set to one (previously zero), and the mean vectors are input as the last data cards in the deck (read in using a 4F6.0 format).

To summarize, the program is initially clustered on a small area and the resulting classes are interpreted. Next, the analysis is extended by using the interpreted results from the small area to classify a much larger area. Since the sequential algorithm is bypassed, relatively much less time is required in analyzing the new data than was required in clustering. Relative times are discussed in the Critique Section.

FINAL RESULTS

Figure 32 is the section of the photomosaic which was analyzed by the CSCP. A photograph of the computer map of the complete area analyzed is depicted in Figure 33, which is approximately 30 miles wide and 26.5 miles long. The 13 classes have been given five Level I names. These are (in order of increasing brightness in Figure 33): (1) agricultural, pasture; (2) forest; (3) agricultural, cropland; (4) water; and (5) urban. Figures 34 through 37 show (1) pasture and water, (2) forest and water, (3) cropland and water, and (4) urban and water. For each of these figures all the symbols but the two of interest were blanked out.

The data analyzed was from E-ERTS-1104-15552 tape 3. The scans were 256-763 and samples (across) were 1-810. Hence, the total area analyzed included 810 x 508 = 411,480 pixels (picture elements), each approximately 57.1 meters wide by 79.1 meters long (in the scan direction). Each symbol, in Figures 33 through 37, occupies a square area so the scale is larger along the scan. This area is approximately 1,800 square kilometers.

Comparison of Figures 32 and 33 indicates that overall the classification was fairly accurate. Some problem areas do exist, but the relative size of these areas is small compared to the area classified. One such problem area is the urban classification of residential areas with a high density of trees. These areas may be classified as agriculture (pasture or cropland). Other problems associated with the classes will be discussed in more detail where the selected areas are presented.

Figure 32. Aerial photograph of test area.

Figure 33. Computer map of test area.

Figure 34. Computer map of pasture and water categories.

Figure 35. Computer map of forest and water categories.

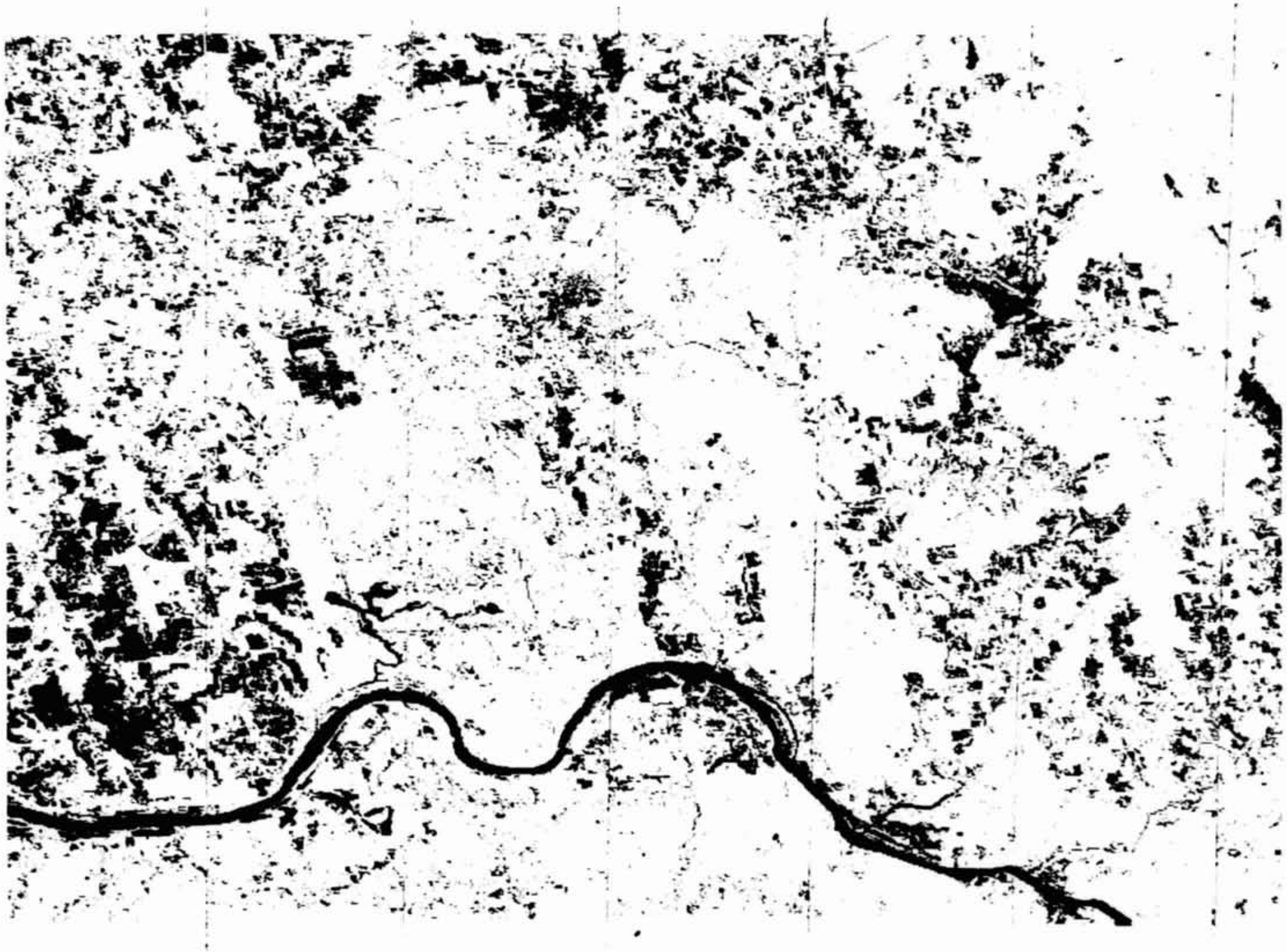


Figure 36. Computer map of cropland and water categories.

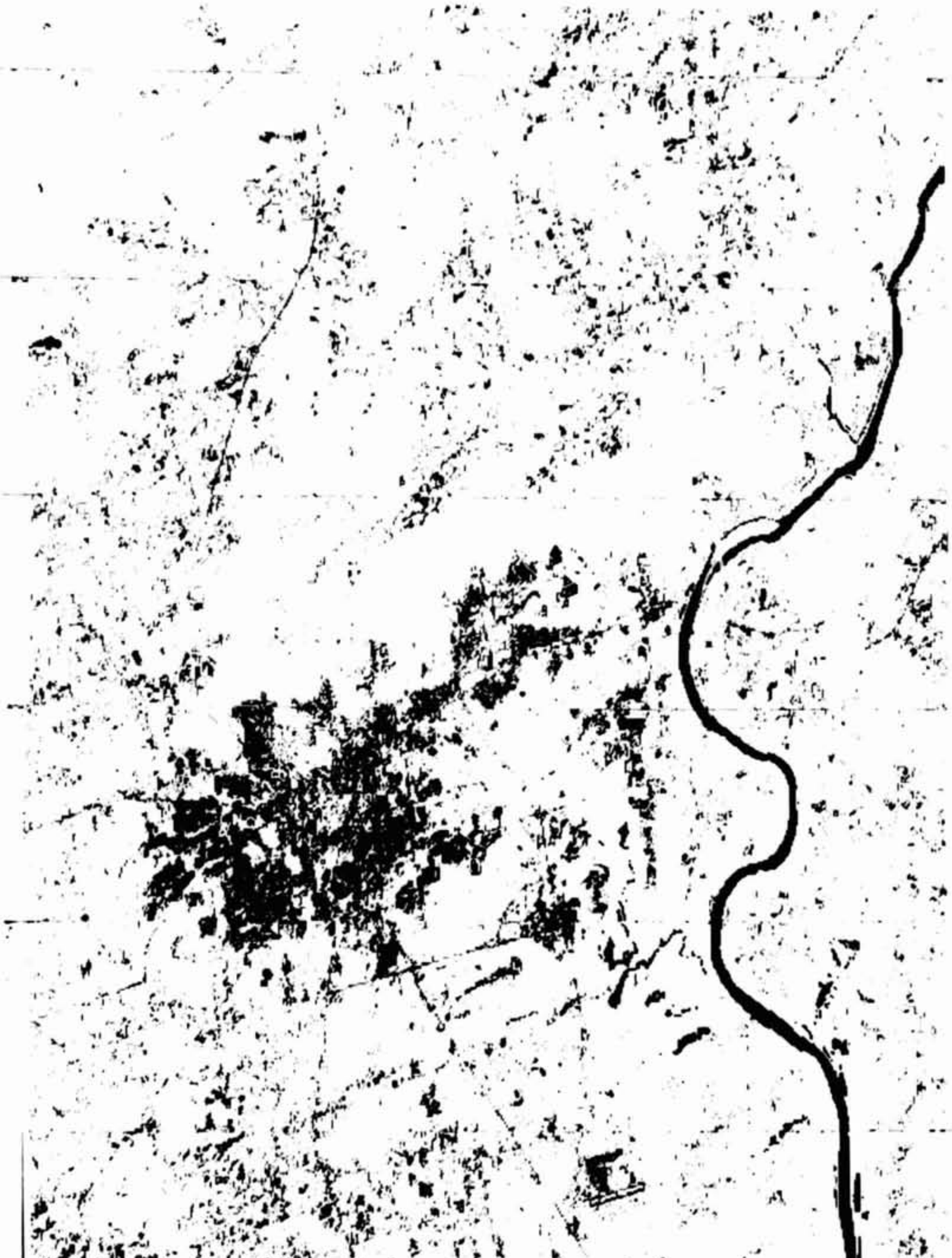


Figure 37. Computer map of urban and water categories.

The input class mean vectors for the final classification are shown in Table 22. The statistics for the classes for the final classification are shown in Table 23. The mean vectors of Table 22 are the mean vectors from the initial clustering run. The statistics depicted in Table 23 are the output of the classification iteration.

Detailed discussion of the entire 411,480 pixel classification will not be undertaken. Instead, two specific areas of the map will be considered. They are the area including and surrounding Marshall Space Flight Center and Redstone Arsenal, and the Jones Valley area of Huntsville. These areas were selected mainly on the basis of familiarity and the easy availability of ground truth.

The MSFC area will be considered first. Figure 38 is a blow up from one of the RB-57 prints showing this area. The color print corresponding to Figure 38 is shown in Figure 13. Figure 39 is the computer map with only the five Level I symbols used. Figure 40 is the double-track boundary map of the same area with different symbols for each of the forest, urban, and cropland categories. Recall that the blank areas are members of the class whose symbol surrounds them. Within the limits of resolution of the data, the classification is fairly good. The only real problem is the separation of the forest and the cropland categories. The cropland category is actually cleared land that does not have lush, low vegetation growing on it. This is not the Level I description of the class, but is actually the category classified by the CSCP. Frequently, this is cropland (e.g. cotton), but at times it may be land that was formerly used for crops but was recently abandoned.

The last case is transitional between cropland and forest land. As the land is abandoned probably the first trees to come in (in the Huntsville area) are red cedar (Juniperus Virginiana) or possibly loblolly pine (Pinus taeda). The initial growth will be sparse and might appear to a remote sensor aboard ERTS to be either forest or crops. Another type of area similar to the above case is grassland planted with tree seedlings. The Army in many areas on Redstone Arsenal has planted pine seedlings. The trees are planted at low density for rapid growth. Even visual discrimination between these areas and some cropland on the RB-57 data is sometimes difficult.

From Figure 40 the forest categories R and Z appear the most dense growth. Class T is less dense and class F is the least dense. Lighting conditions on the slopes of the mountains also have a considerable effect. Dense forest on a sunny southeastern slope may appear similar to a less densely forested area located upon level topography.

The area just north of the 4200 building complex (MSFC area) is a mowed grass area with a north-south running line of trees (Fig. 38). Since from the RB-57 data this area looks similar to crop land the area should have been classified as crop. Instead, it was classified as the least dense, F forest category. The reason F is named forest rather than crop is that the class is found frequently in dense forest areas on sunny mountain slopes.

TABLE 22. INPUT MEAN VECTORS FOR THE K-MEANS SECTION OF THE CSCP

Class No.	Channel 1	Channel 2	Channel 3	Channel 4
1	20.804	12.958	7.166	1.560
2	22.645	16.662	35.261	20.781
3	20.279	15.884	26.801	15.770
4	23.055	15.818	41.382	24.664
5	24.683	21.429	28.969	15.322
6	20.234	15.957	17.980	9.159
7	23.438	21.395	24.490	12.448
8	30.222	27.440	32.715	16.151
9	18.327	13.574	21.872	12.994
10	17.204	11.829	16.103	8.887
11	24.284	20.742	16.581	5.722
12	22.200	13.702	48.042	29.727
13	18.111	13.015	19.256	11.186

TABLE 23. CLASSIFICATION STATISTICS

Iteration No. 1 Improved Cluster Centers					Jetplex TC Paint Rock Pasture	
Class	Sym.	Nr. Sample	Spectral Mean Values			
1	W	4989	20.610	12.820	7.182	1.580
2	/	27438	22.687	17.090	34.176	20.001
3		73098	20.460	16.045	26.561	15.460
4	/	8085	23.066	15.934	41.042	24.328
5		35093	24.479	21.164	29.609	15.812
6		27224	20.378	16.814	19.339	10.084
7		46850	22.475	20.383	24.094	12.449
8		8919	30.166	27.576	32.653	16.083
9		103418	18.873	14.254	22.403	13.079
10		23617	17.294	11.848	15.844	8.652
11	W	1287	24.261	20.545	16.129	5.169
12	/	2341	22.196	13.730	47.841	29.501
13		50741	18.147	13.043	19.306	11.177
Class	Sym.	Nr. Sample	Spectral Standard Deviations			
1	W	4989	1.435	1.395	2.134	1.293
2	/	27438	1.613	2.055	2.088	1.505
3		73098	1.346	1.447	1.995	1.490
4	/	8085	1.671	2.062	1.875	1.549
5		35093	1.852	1.902	1.841	1.461
6		27224	1.080	1.563	1.564	1.184
7		46850	1.660	1.825	1.612	1.196
8		8919	3.985	4.492	2.467	2.234
9		103418	1.137	1.410	1.223	1.069
10		23617	1.093	1.151	1.655	1.266
11	W	1287	2.145	2.465	2.817	2.22[illegible]
12	/	2341	1.395	1.255	2.859	2.351
13		50741	0.981	1.095	1.031	0.847

Figure 38. Photograph of MSFC area.

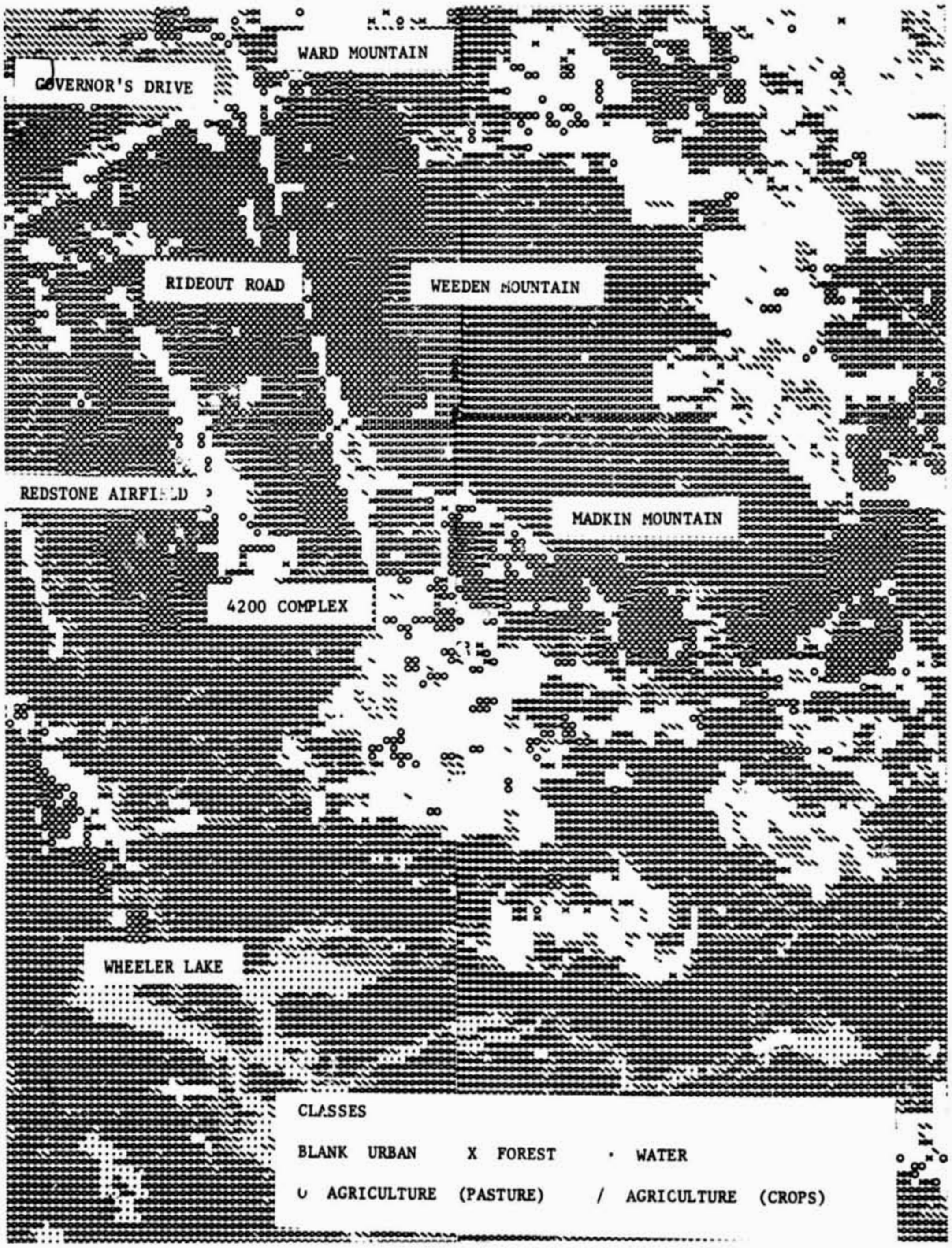


Figure 39. Computer map of MSFC area.

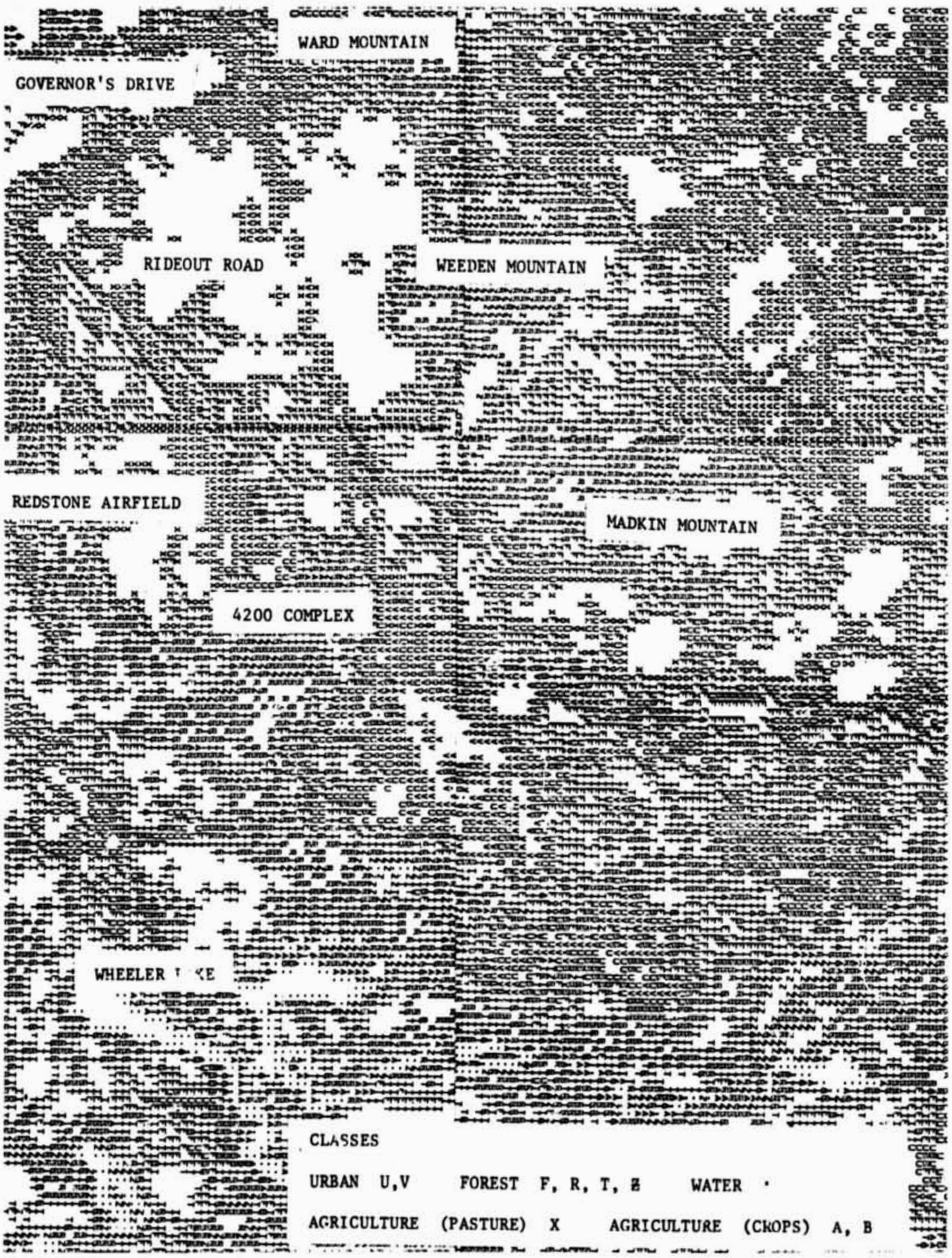


Figure 40. Double-track boundary map of MSFC area.

If the 78 distances between the 13 classes are ordered, the 2 distances between the F category and the 2 crop categories rank fifth and sixth. These classes are close enough so that the condition of illumination holds the key as to which classification of a sample will occur.

The Jones Valley area is a large cattle grazing area planted entirely with grass (Kentucky 31 Fescue). By far the most striking features in the IR channels of the fall ERTS imagery are areas of cattle grazing. These areas possess an extremely high IR reflectance, which enables the CSCP to make a ready classification.

Figure 41 is a blown up section of one of the RB-57 images showing the Jones Valley area. Figure 42 is the classification map with the five Level I symbols. Figure 43 is the double-track boundary map with different symbols for the urban, forest, and crop categories. Compare Figures 42 and 43 with Figures 4 and 5 also.

For a sample of how good the classification can be, note the four urban symbols in the center of the large cattle grazing area. These cover the area of the farmhouse and other farm buildings. Approximately 11 scans above and 4 samples to the left of this area is a single forest classification. This is a small group of pecan trees whose area is not quite the size of a resolution element. The areas classified urban on the northern and western fringes of the pasture are accurately classified residential sections. The only misclassifications of any note are located on the small mountain west of Jones Valley. The classification is B crops where it should be urban. This residential zone has many trees and this misclassification is understandable. Notice that the area surrounding these B classified areas are the expected less dense F and T forest categories.

CRITIQUE

To compare the time required for the unsupervised mode with that required for the supervised mode, an area three-fourths the size of the total 411,480 pixel area was classified. The IBM 7094 time required was approximately 3 hours and 50 minutes with three iterations. In practice, an area one fourth this size is probably all that is necessary for clustering. The total IBM 7094 time for the iteration or classification map was 1.5 hours.

Due to limited manpower no effort has been made to streamline the CSCP. Certainly some of the subroutines in the program are not as efficiently programmed as is possible, and, with some rearrangements, there is no doubt that considerable time and storage could be saved.

Classification of the data with the CSCP is generally very good, but could be improved. In Reference 9, the K-means classification is not based entirely on a Euclidean minimum distance, but is actually the Euclidean distance normalized by a "characterized" variance. This characterized variance is simply the magnitude of the class

Figure 41. Photograph of Jones Valley area.

variance vector. The reason each distance is not normalized using the vector variance is that the time required, with the present efficiency of the CSCP, would be prohibitive. The characterized variance is a good normalization factor if all components of the class variance vector are approximately the same. With the Huntsville ERTS data, experience has shown that most of the classes satisfy this condition readily. With the characterized variance the classification accuracy of the CSCP would probably be improved considerably.

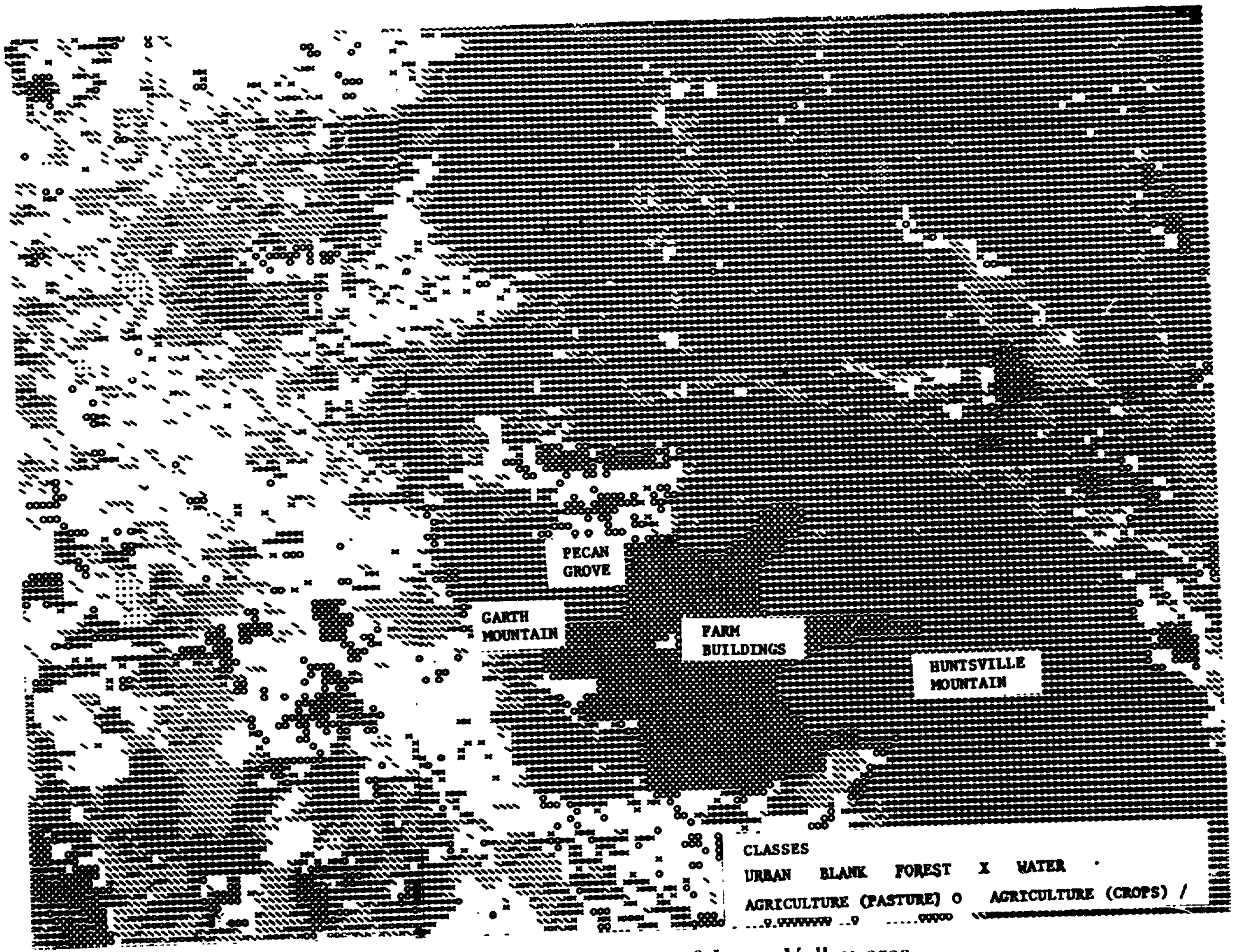


Figure 42. Computer map of Jones Valley area.

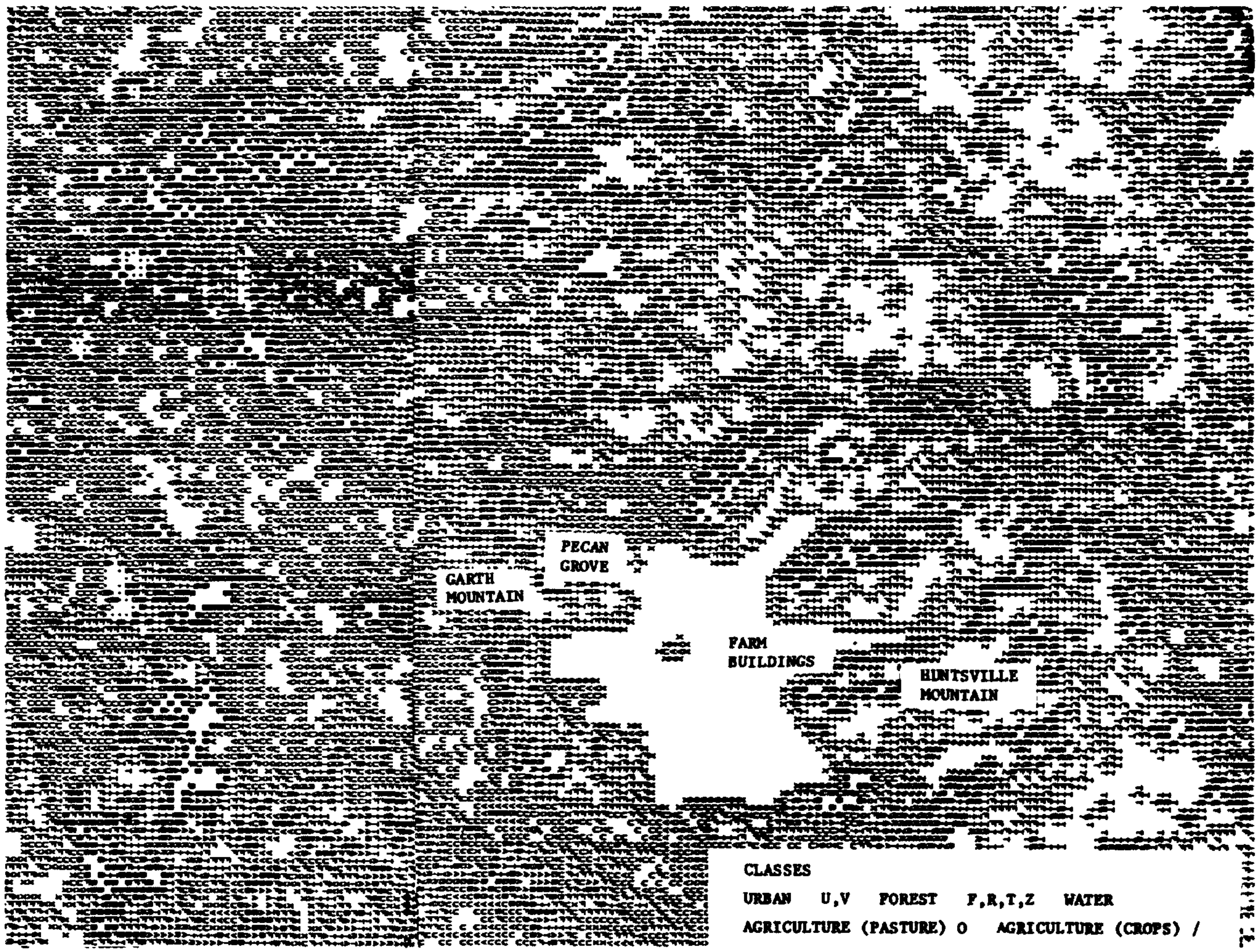


Figure 43. Double-track boundary map of Jones Valley area.

Distinctions and Similarities of the Composite Sequential Clustering Program (CSCP) and the Spatial and Spectral Clustering Program (SSCP)

Although the same end products are desired, the initial efforts on both programs are different. In order to establish cluster populations, the CSCP uses spatial information only in one direction, by considering consecutive samples within a scan. Actually the spatial information is secondary, since statistical tests, based upon spectral information, are used to decide which samples belong to a cluster. As a consequence, no spatial information is used in relating samples in different scans, but only spectral information. Since data samples for each cluster are acquired from all over the data set, it is often difficult to relate the make up of a cluster to the ground truth, and because the cluster populations are continuously recalculated while reading through the raw data tape, there is no guarantee that a sample originally included in the cluster at the beginning of the tape would still belong to that cluster when the end of the raw data tape is reached. In other words, the clusters and their statistics are highly dependent on where the analysis is initialized in the data set. In order to overcome this problem, an iteration procedure is used to recalculate the cluster statistics until the clusters and their statistics stabilize. In producing a classification map, every data sample is classified as belonging to one of the classes.

In producing a boundary map, the SSCP converts spectral information to spatial information in two directions. The locations of the clusters are then defined on the boundary map, which provides the visibility necessary in relating the clusters to the ground truth. The formation of the clusters is not dependent on where the analysis is initiated, and, therefore, no iteration is used. Also, not all of the data samples are classified in producing a classification map. The samples not belonging to any of the classes, based upon the input parameters for the decision rule, and left unclassified.

Both programs use a merging procedure which determines the number of classes. The CSCP has an automatic spectral merging procedure for keeping the number of classes equal to or less than 30 and a manual merging procedure for combining classes. The SSCP has an automatic spectral merging procedure, but it is not based upon the number of classes. The manual merging procedure is done by assigning two or more classes the same computer printout symbol.

There is always a tradeoff between the degree of complexity and flexibility, and how automatic a program can be made. In this respect, the CSCP is more automatic and the SSCP is more flexible and complicated to run. Using both programs to analyze a data set plus reference to some visual photographic coverage of the area does, however, provide more visibility to what is going on in the data. For example, compare the class mean vectors in Tables 4, 8, 19, with Table 22, and the classification maps shown in Figures 28, 29, 30, and 31 with the maps shown in Figures 33, 34, 35, 36, and 37.

Mr. Charles Dalton, of the Aerospace Environment Division, has critically reviewed both programs and made recommendations for their improvement. His ideas have been published in References 13 and 14, which provide a more detailed basis for comparison.

It is difficult to accurately compare the running times of both programs, since a different number of classes were obtained and they were run on different size areas. Nonetheless, a rough comparison can be obtained based upon the following numbers. The CSCP was originally clustered on a 411,480 sample size data set and obtained 15 classes in 3 hours 50 minutes with 3 iterations. The SSCP was run on a 257,550 sample size data set and obtained 26 classes in 1 hour 17 minutes, which includes producing the boundary map. In order to compare the classification time only, the CSCP was run with only 1 iteration of 411,480 sample data set and ran 1 hour and 30 minutes for 13 classes. The SSCP ran for 24 minutes and 35 seconds on the 257,550 sample data set with 26 classes and for 28 minutes and 38 seconds using 38 classes.

General Comments and Recommendations

At this time it might be worthwhile to review what the report on the computer analysis did and did not cover. The report is a demonstration of what can be done with the data, but the application part is somewhat lacking. This was mainly because there was no readily available user to work with, but an attempt was made by the authors based on their experiences with users to anticipate what a potential general land survey user might like to have in terms of results. It is hoped that this report will provide a common basis for discussions concerning the specific needs of potential users. In this respect, the utilization of the computer analysis was directed more toward user agency, rather than the man on the street, with the hope that the man on the street would ultimately derive the benefits from the interpretations of such an analysis. It is envisioned that the results of a similar type analysis could eventually be used as valuable inputs to an information management system as a basis for making future decisions on land use and environmental impacts.

As a result of the experience obtained in performing the computer analysis, several recommendations can be made for immediate specific efforts. First there is the need to be able to produce a geographically accurate map from the classification results, and second, an adequate display facility is needed. Thirdly, to improve the accuracy of the analysis, seasonal data needs to be incorporated in the analysis. For example, if ERTS data were obtained for four seasons and classification maps were made for each season, it would be possible to identify those areas that were plowed and label them specifically as cropland. In addition, if the planting and harvesting dates were known for the various crop types, the information could be used in conjunction with the classification map to distinguish between different crop types. Another alternative would be to register and combine the 4 ERTS tapes into one date tape containing 16 channels, and analyze all 16 channels simultaneously. The feature signatures would then contain information as a function of time as well as spectral information, and provide a means of detecting changes that had occurred in the ground scene.

Extending the analysis over 4 tapes to classify an entire ERTS image does not appear to be a problem, but it is not known what problems would be encountered in extending the analysis from image to image to cover an entire state. Assuming that no problem exists in using classes obtained from one image to classify another image, that 4 channels of data are used, that 13 classes are desired and use, and that the IBM-7094 is used, a land use survey for the State of Alabama using the CSCP could be completed in a minimum amount of time estimated to be approximately 100 computer hours. At a current rate of $60/hour, the survey would cost a minimum of $6000, or roughly 13¢ a square mile. Using SSCP under the same assumption, except that 38 classes are desired and used, the survey could take a minimum amount of time estimated to be approximately 52 computer hours. Thus, the survey could cost a minimum of $3120 or roughly 6¢ a square mile. The most critical part of the analysis is establishing the signatures of the desired features, which could considerably alter the computer time either way depending on how many classes are used.

Before a land use survey of this magnitude is attempted, it is recommended that considerable attention be given to the type of features that are desired and can be identified in the data, and, finally, both programs need to be re-examined to minimize their running times.

George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Marshall Space Flight Center, Alabama, April 1974

APPENDIX

GROUND TRUTH IMAGERY AND SUPPLEMENTARY LARGE SCALE PHOTOMOSAICS OF THE LAND USE STUDY AREA

While conducting this land use study, considerable ground truth imagery was obtained or collected by the participants. Some of the resulting aerial photomosaics and individual black and white ground-obtained photographs, as well as photo indexes of ground-obtained color imagery, are included.

Basically this imagery was used in various ways to help interpret actual land use or conditions from the aerial photography and the automated classification scheme printouts. By including small scale photographs of this ground truth information in the report, it is hoped that interested persons desiring to use the imagery will contact one of the authors for access to it.

The following items are included in this appendix:

1. Figure 44. Aerial photomosaic of Elk River, S.W. portion.

2. Figure 45. Ground truth imagery of S.W. portion of the Elk River.

3. Figure 46. Aerial photomosaic of Elk River, N.E. portion.

4. Figure 47. Ground truth imagery of N.E. portion of Elk River.

5. Figure 48. Aerial photomosaic of Jones Valley and East Huntsville, Ala.

6. Figure 49. Photo index for ground truth imagery covering Jones Valley rangeland, dated Nov. 10, 1973.

7. Figure 50. Photo index for ground truth imagery covering Jones Valley rangeland, dated Nov. 17, 1973.

8. Figure 51. Photo index for ground truth imagery covering Jones Valley rangeland, dated Nov. 24, 1973.

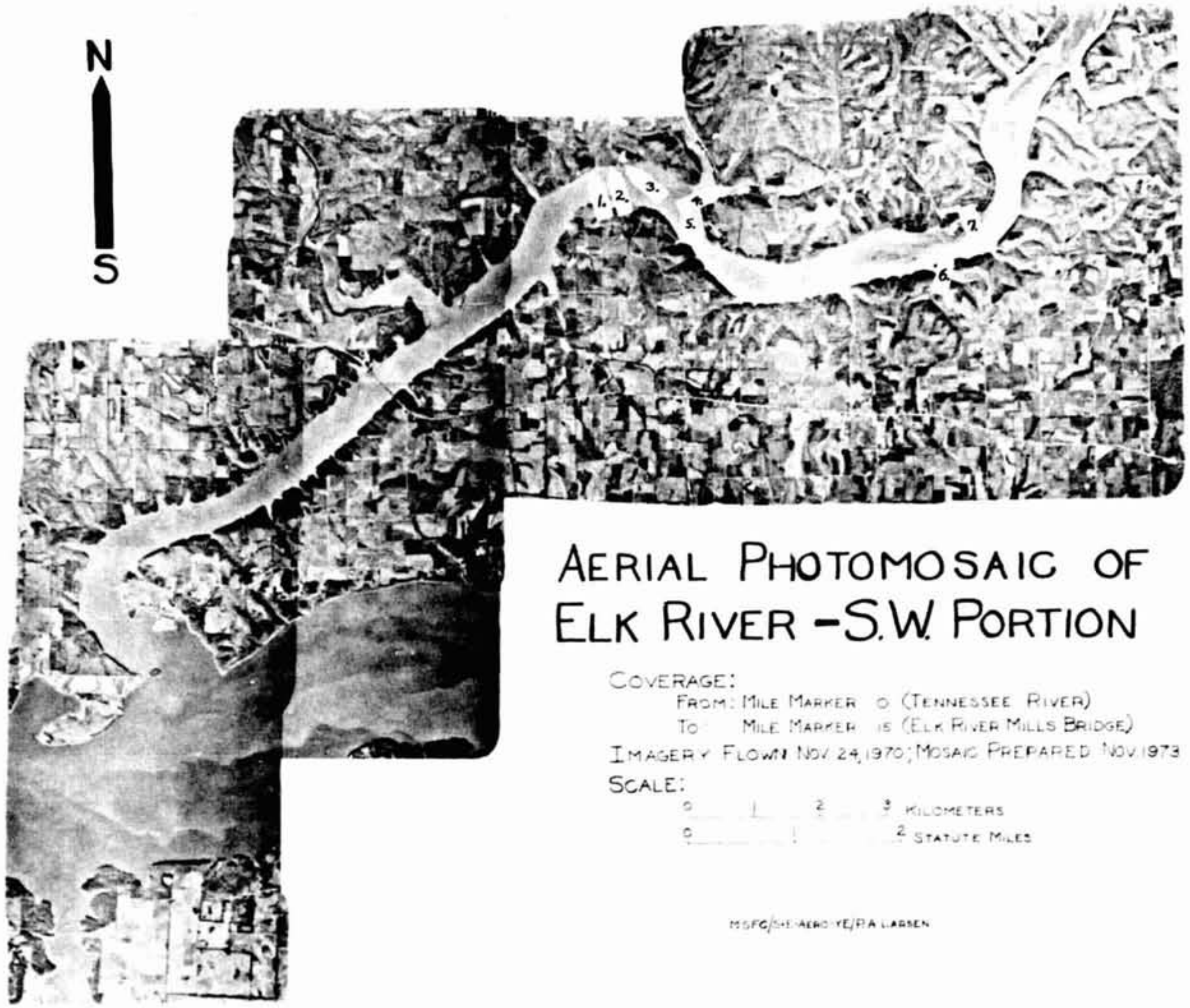


Figure 44. Aerial photomosaic of Elk River, S.W. portion.

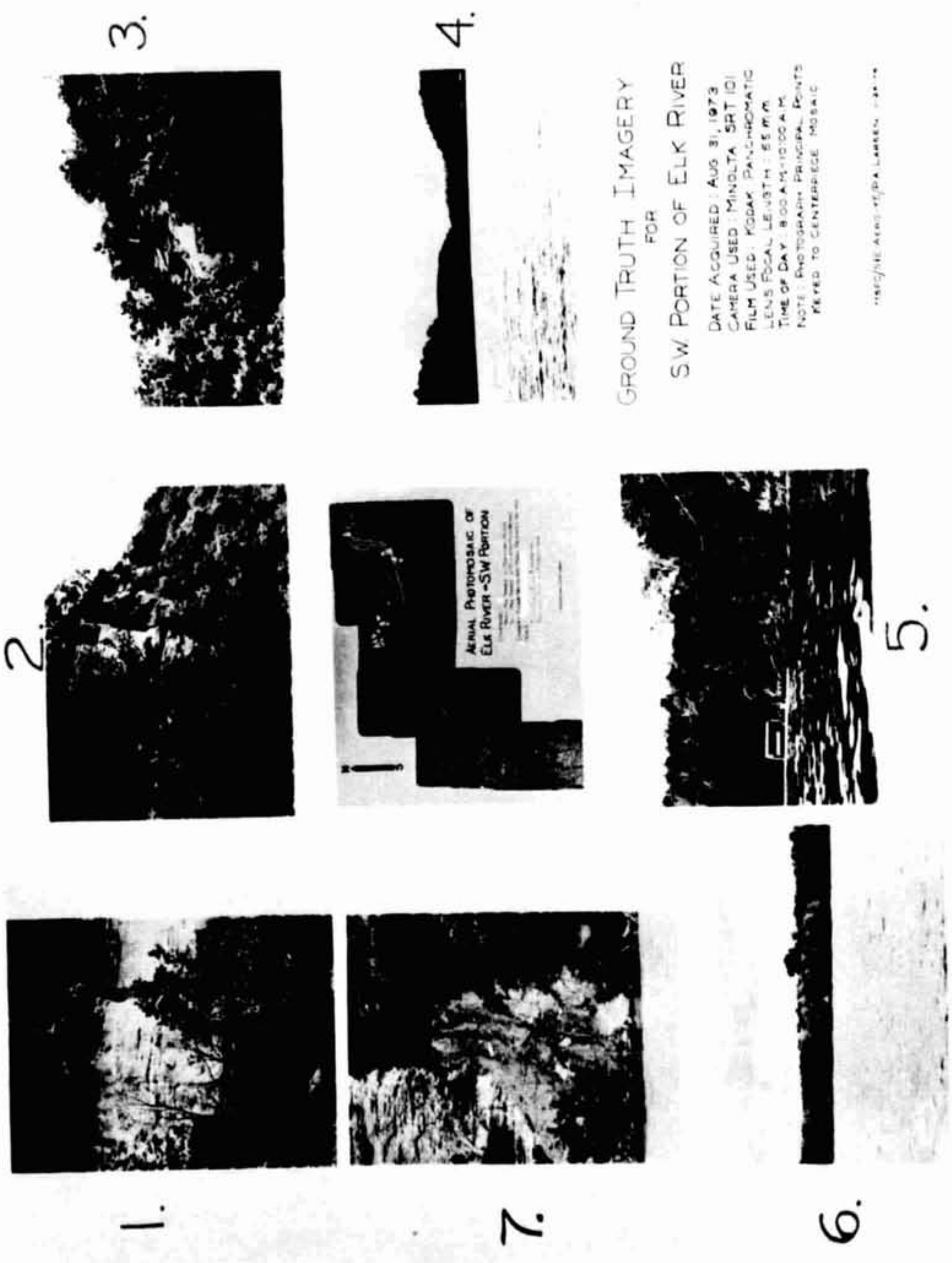


Figure 45. Ground truth imagery for S.W. portion of Elk River.

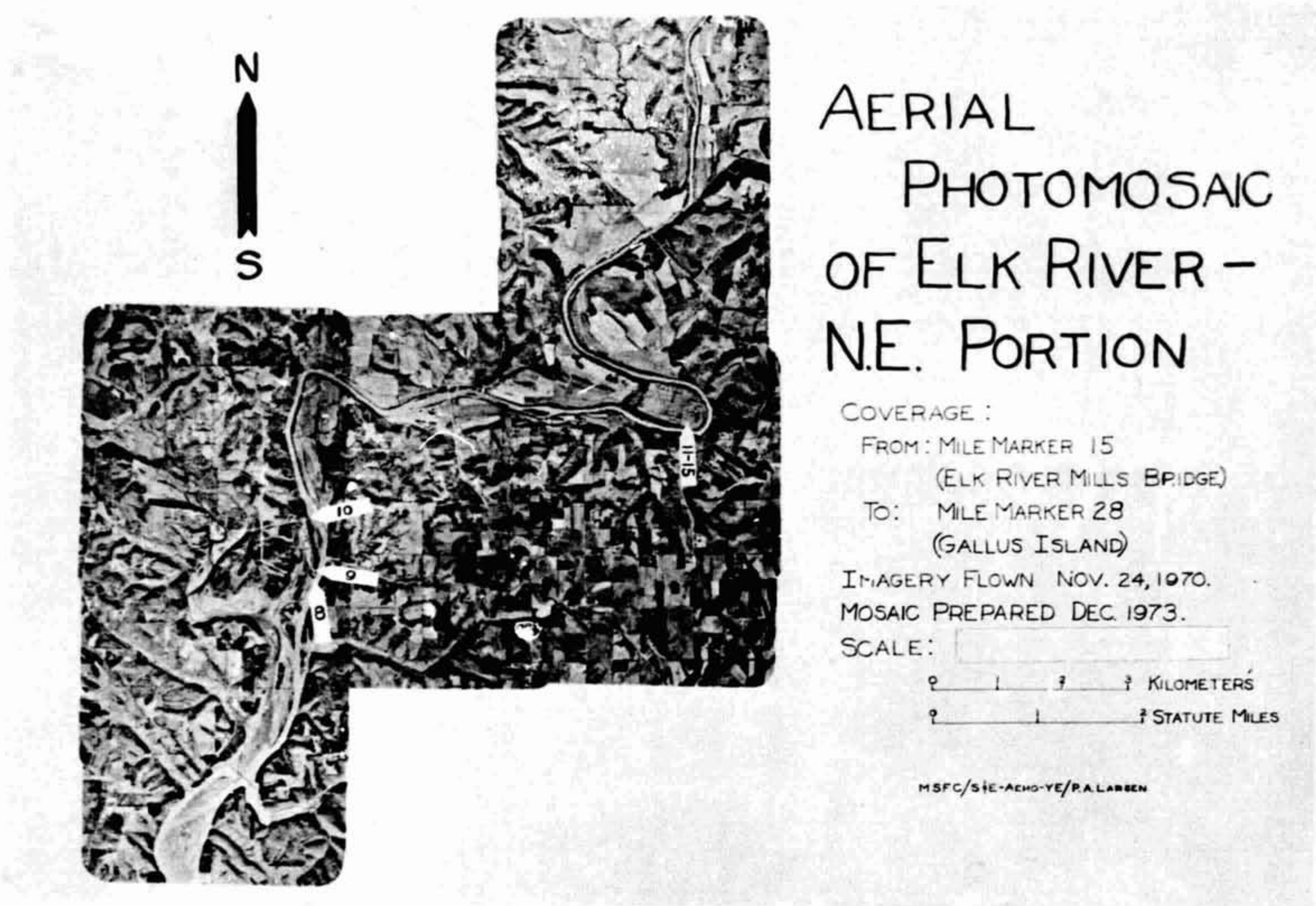


Figure 46. Aerial photomosaic of Elk River, N.E. portion.

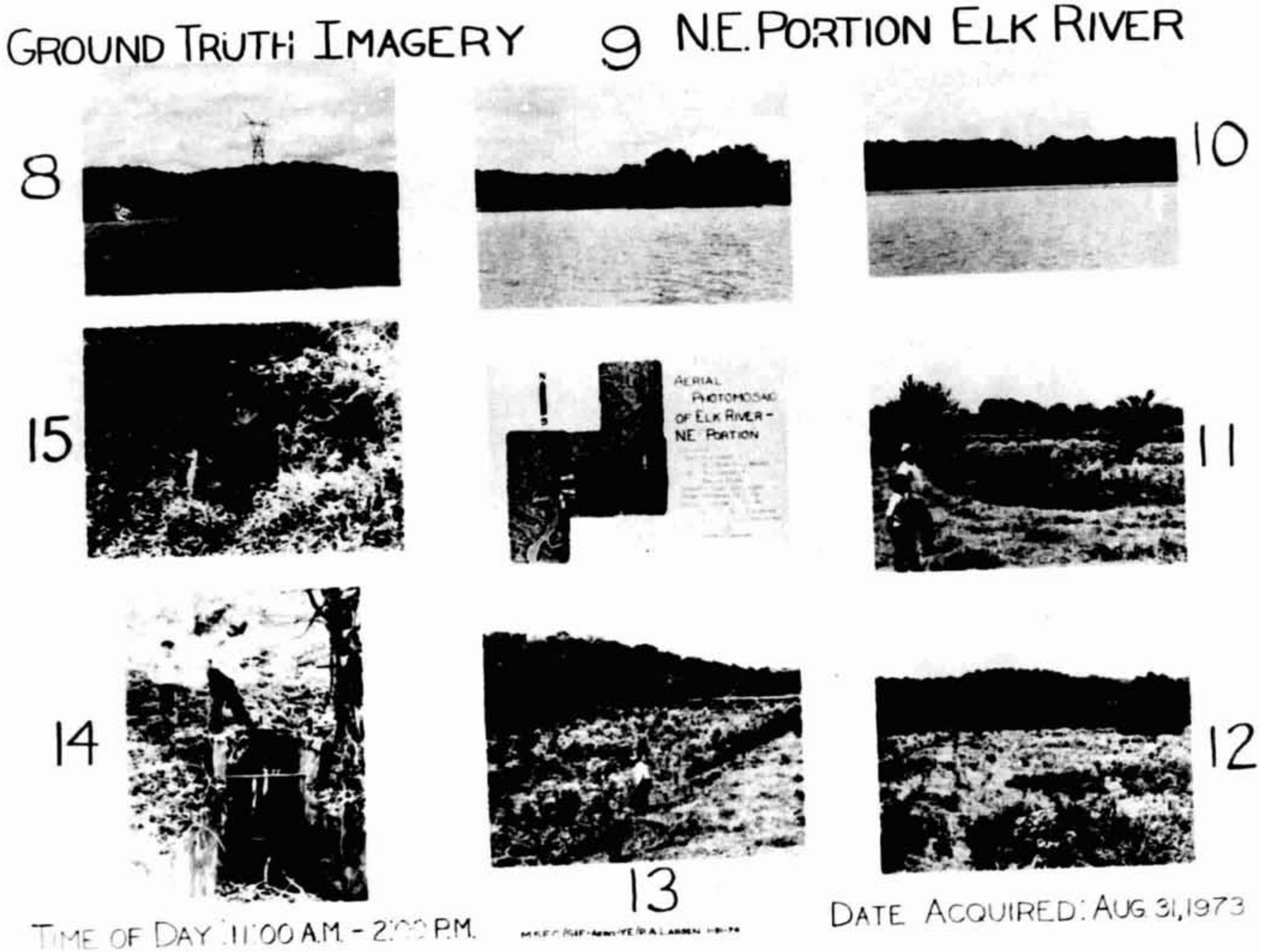


Figure 47. Ground truth imagery for N.E. portion of Elk River.

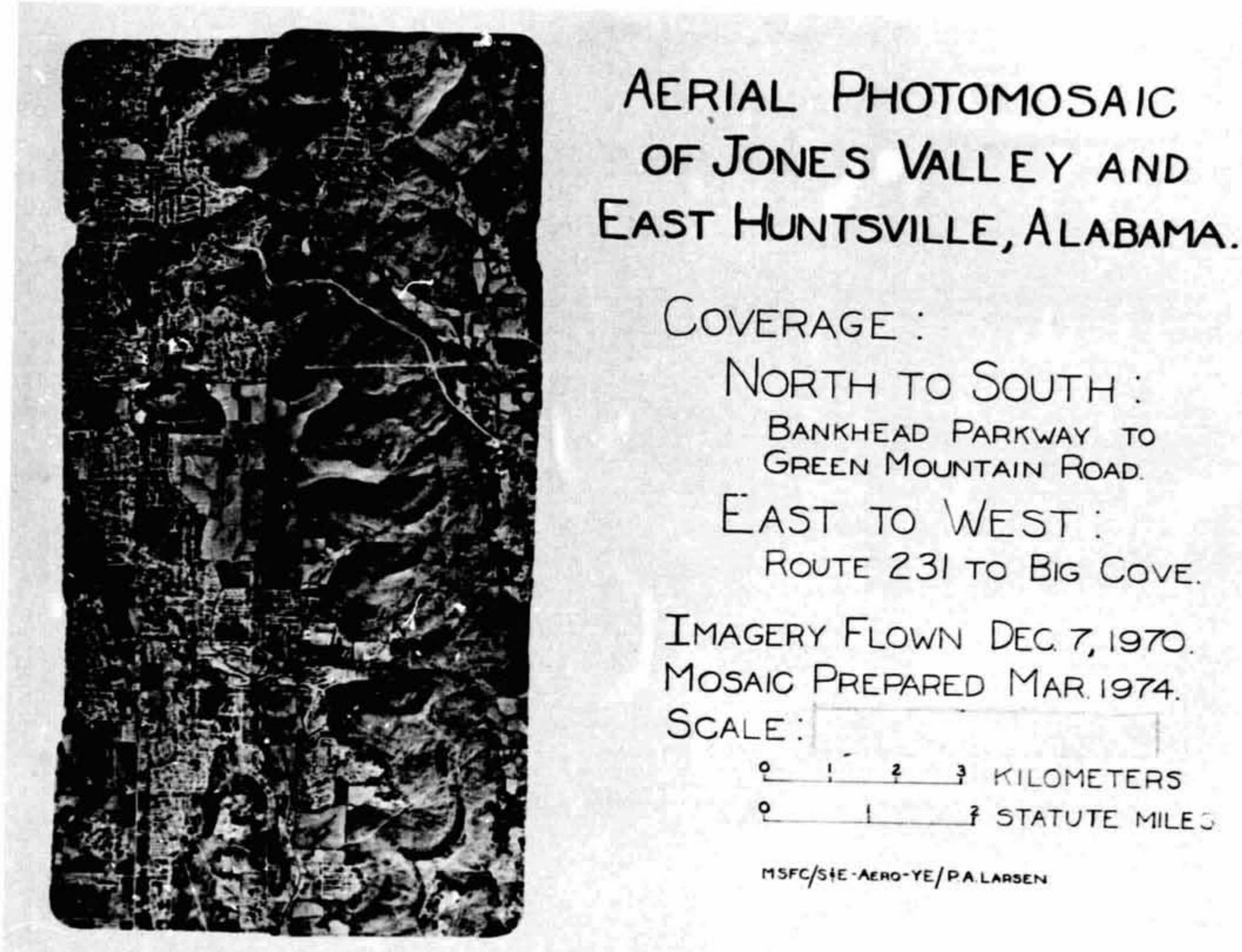
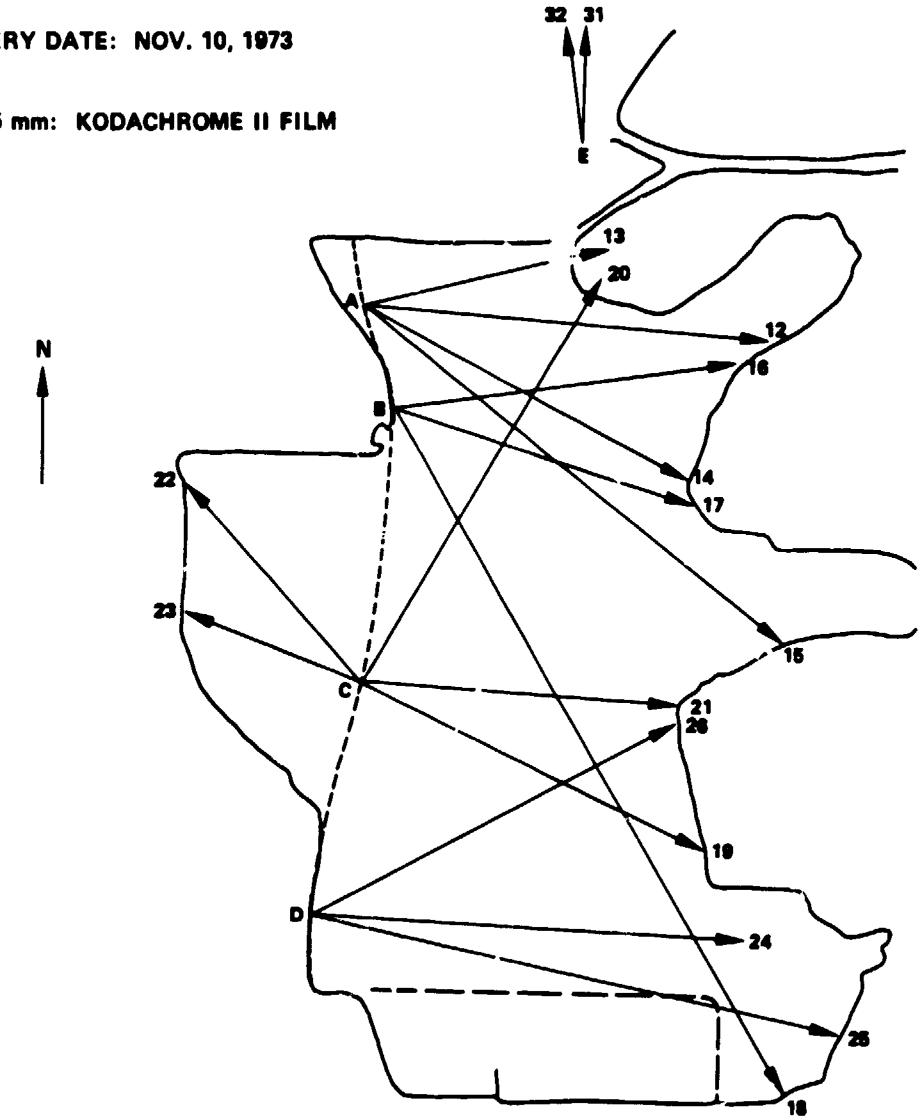


Figure 48. Aerial photomosaic of Jones Valley and East Huntsville, Alabama.

IMAGERY DATE: NOV. 10, 1973

f = 135 mm: KODACHROME II FILM



NOTES:

1. IMAGERY RECORDED FROM POINTS A, B, C, D, AND E.

2. VECTOR NUMBERS ARE SLIDE NUMBERS.

3. ARROWS SHOW PRINCIPAL POINT LOCATIONS.

P. A. LARSEN
NASA–MSFC
S&E–AERO–YE

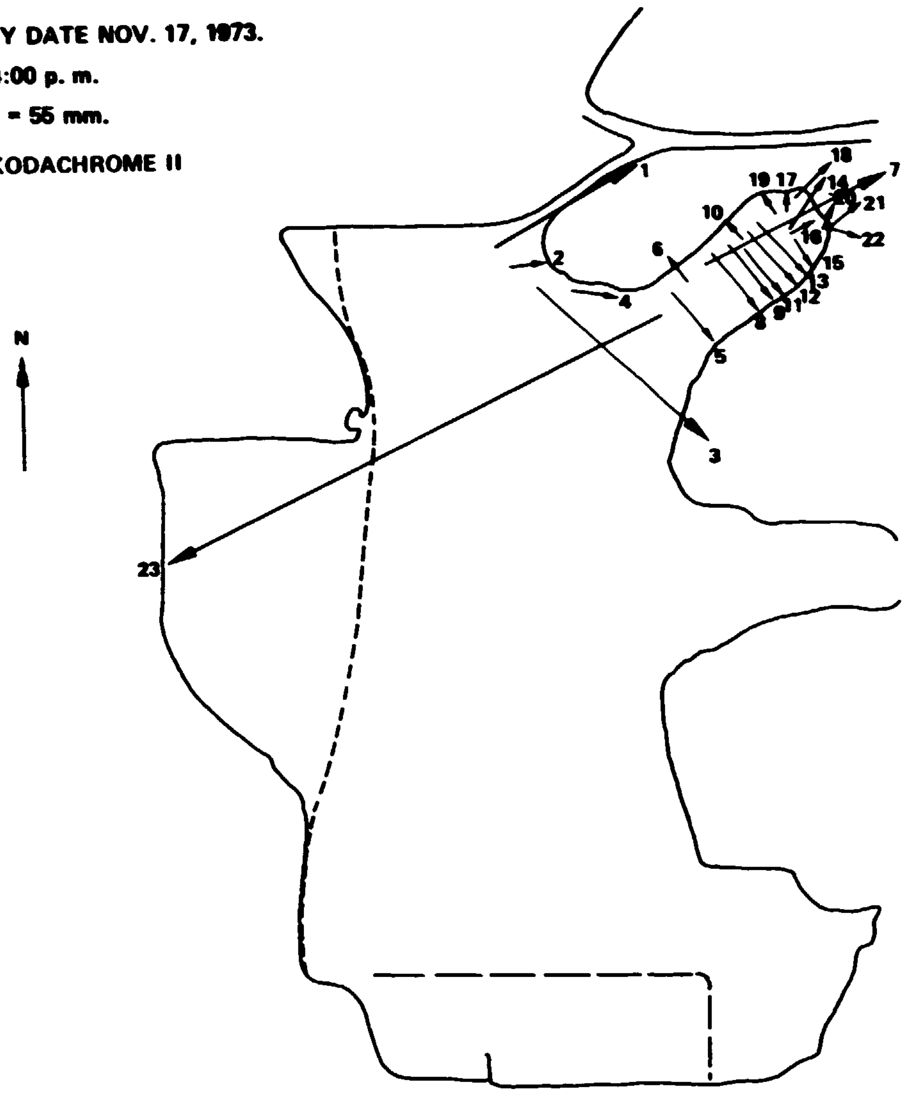
Figure 49. Photo index for ground truth imagery covering Jones Valley rangeland, dated Nov. 10, 1973.

IMAGERY DATE NOV. 17, 1973.

TIME: 4:00 p. m.

LENS: f = 55 mm.

FILM: KODACHROME II



NOTES:

1. VECTOR NUMBERS CORRESPOND TO SLIDE NUMBERS.

2. ARROWS SHOW PRINCIPAL POINT LOCATIONS.

P. A. LARSEN
NASA–MSFC
S&E–AERO–YE

Figure 50. Photo index for ground truth imagery covering Jones Valley rangeland, dated Nov. 17, 1973.

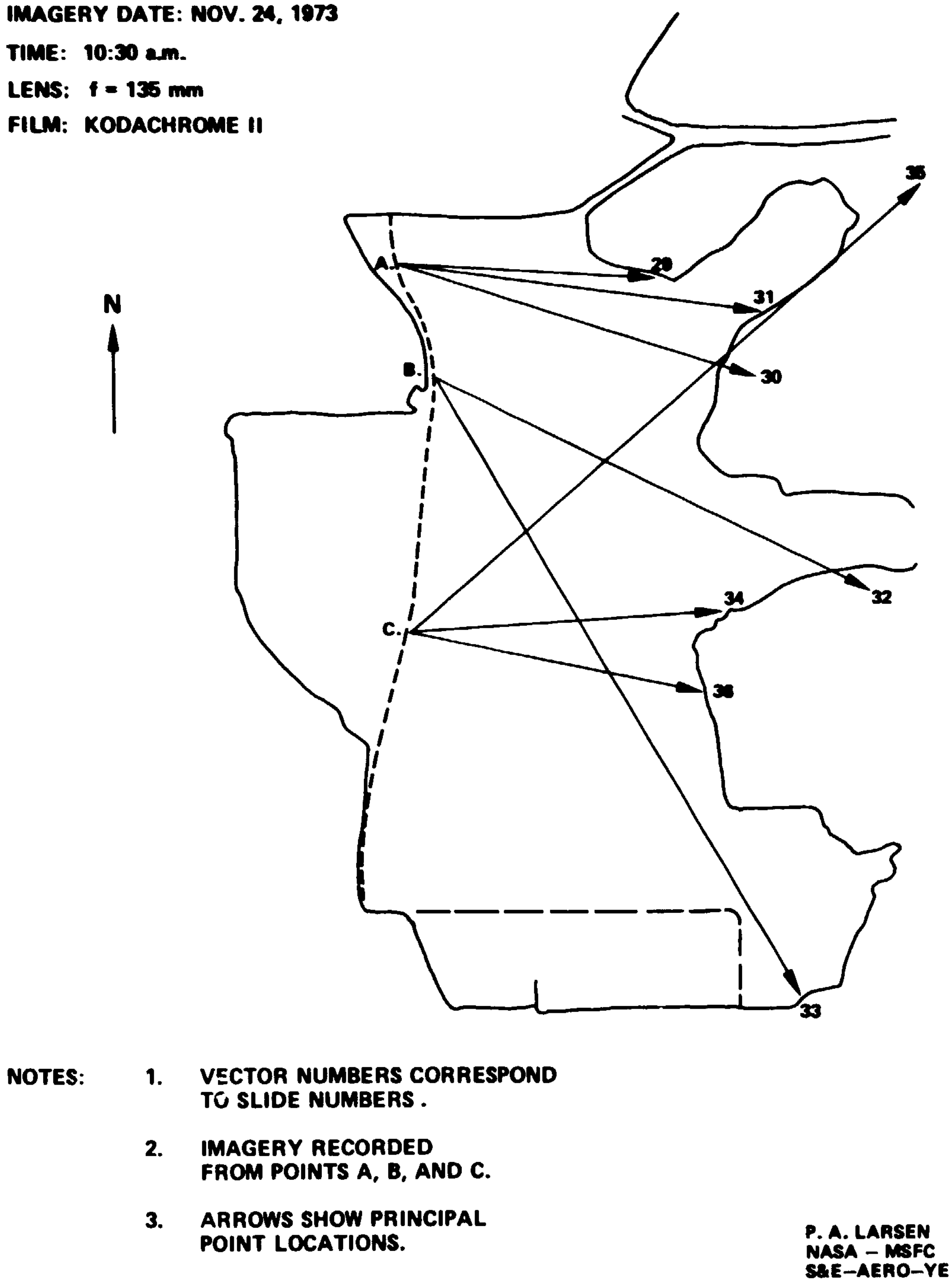


Figure 51. Photo index for ground truth imagery covering Jones Valley rangeland, dated Nov. 24, 1973.

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